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when inserted in supersonic airflow, to
determine its dependence on pressure and velocity

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INVESTIGATIONS OF AN ELECTRICAL GLOW DISCHARGE,
WHEN INSERTED IN SUPERSONIC AIRFLOW,
TO DETERMINE ITS DEPENDENCE ON PRESSURE AND VELOCITY

by
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University of Minnesota
Minneapolis 14, Minnesota

July 28, 1949

A Thesis Submitted to the Faculty of
the Graduate School in Partial
Fulfillment of the Requirements for
the Degree of
Master of Science

7/12/57
5/2/57

Investigation of an electrical circuit diagram.
The diagram is of a circuit diagram.
to determine the conditions of operation and voltage.

at 1000 hours in the morning

Department of Agriculture, Washington

Director, of Agriculture
Washington, D. C.

July 12, 1957

A copy is submitted to the Bureau of
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SUMMARY

It has been found in this preliminary investigation that an electrical glow discharge from a sharp point, when inserted in supersonic airflow ($M = 1.0$ to $M = 3.0$) is sensitive to the following conditions.

1. The glow current is definitely pressure sensitive at supersonic velocities.
2. Any Mach number change from $M = 1$ to $M = 3$ effects the glow current.
3. A greater voltage is required to maintain a given current for larger electrode spacings, a larger size wire, and a positive wire polarity.
4. Platinum wire of 0.003-inch minimum diameter could be used in this investigation because any smaller size wire bent when it was inserted in supersonic airflow.
5. Current flow from 10 to 80 microamperes gives enough glow discharge for this experiment ($M = 1.0$ to $M = 3.0$).
6. The shape of the plate and the material from which it is made effect the current flow.
7. The glow changes in size with changes in Mach number.
8. The glow changes in size with change in static pressure.
9. This device adapts itself for use as a static pressure measuring instrument and possibly as a Mach number recorder.

It has been found in this preliminary investigation that as electrical glow discharges from a sharp point, when initiated in a vacuum at $p = 1.0$ in $H = 5.0$, is sensitive to the following conditions.

1. The glow current is relatively constant regardless of electrode separation.
2. Any sharp corner between $p = 1$ to $p = 5$ allows the glow current.
3. A greater voltage is required to initiate a glow current for larger electrode spacing, a larger wire size, and a positive wire polarity.
4. Filament wire of 0.003-inch diameter diameter could be used in this investigation because any smaller wire size would cause it to be initiated in a vacuum at $p = 1.0$.
5. Current flow is to be 50 milliamperes gives enough flow discharge for this experiment ($p = 1.0$ to $p = 5.0$).
6. The shape of the glass and the material from which it is made affect the current flow.
7. The glow changes in size with changes in gas pressure.
8. The glow changes in size with changes in electric field.
9. This device might be used as a static pressure measuring instrument and possibly as a gas density indicator.

INTRODUCTION

Frank David Werner¹⁾ in his investigation of the possible utilization of an electrical glow discharge as a means for measuring airflow characteristics, found that the glow current from a sharp point is markedly pressure sensitive, somewhat dependent upon velocity, slightly dependent upon humidity, and apparently not dependent upon ordinary temperatures. His investigation was made through a velocity range from zero to 400 feet per second or a Mach number range of from zero to about 0.4.

The primary endeavor in the writer's investigation was to make a preliminary exploration to determine if such a glow would function at all in supersonic airflow, to design apparatus with which an electrical glow discharge from a sharp point could be studied, and also to determine if the glow is pressure or velocity dependent at Mach numbers greater than one. The Mach number range used in this investigation was from 1.0 to 3.0. The facility in which this investigation was carried out was constructed by the writer and Lt. Cdr. F. X. Timmes (graduate student) at the University of Minnesota Aeronautical Laboratories at the Rosemount Research Center, Rosemount, Minnesota.

Since this is the first time an electrical glow discharge from a sharp point has been inserted in supersonic airflow to investigate its dependence on pressures and Mach numbers, it is to be expected that the results obtained will have some experimental errors because of inadequate instrumentation and should be used only as a

INTRODUCTION

When David Heston, in his investigation of the possible utilization of an electrical line between the two points for measuring electric resistance, found that the line carried a heavy load in ordinary practice, he was unable to obtain the necessary accuracy, because of the heavy load, and especially the dependence upon the line, his investigation was made through a relay, which was used to cut out the load or a small number range of line, as in the case of a relay.

The relay, which is in the center of the investigation, was made a preliminary investigation to determine if such a line would be useful in all its applications. It was designed especially with which an electrical line between two points could be studied, and also to determine if the line in question or velocity dependent at each point. The line was found to be useful in all its applications and from 1.5 to 2.5. The results of this investigation are carried out and summarized by the author and Dr. E. A. Wilson (University of California) in the University of California, Berkeley, California. The following are the results of the investigation, Heston, Heston.

When this is the first time an electrical line is used, it is a heavy load, and the results are expected to be similar. It is to be expected that the results obtained will have some experimental errors, because of the heavy load, and the results will be only a

guide for later and more elaborate studies. Experience in designing and using equipment to make this investigation should lead to the development of more accurate instrumentation, and to the elimination of some of these errors. However, the general trend of dependence upon Mach number and pressure of the electrical glow discharge from a sharp point will be shown in this investigation.

For this study it was decided to construct a special small size wind tunnel instead of using any of the University's full-scale tunnels. The reason for this decision was the necessity for more flexibility during investigations even though the accuracy of ultimate results may be lowered. Since this was the first use of the sharp point glow discharge in supersonic airflow, many adaptations were more convenient in this setup than in the full-scale tunnel. It is logical that the ultimate check of the data obtained in this tunnel would have to be made in a full-scale tunnel, but that step is beyond the scope of this paper. A single step attempt to use the needle in a full-scale tunnel is shown in the appendix.

The writer is grateful to Professor John D. Akerman for his advice and general direction of the research. Mr. Frank D. Werner was very helpful in the actual design of all the electrical equipment. Professor J. W. Braithwaite was of great assistance in the design and construction of the supersonic wind tunnel.

gains for later and more extensive studies. Improvements
 in designing and using equipment to make this investigation
 should lead to the development of more accurate instrument-
 ation, and to the elimination of some of these errors.
 However, the present trend of cooperation with these workers
 and presence of the electrical give message from a
 sharp point will be shown in this investigation.
 For this study it was decided to consider a
 special case also with some interest of other work in
 the University's laboratory. The reason for this
 decision was the necessity for more limited study
 investigations over the range of values of
 units may be observed. Since this was the first use of
 the sharp point and design in previous studies,
 many experiments were more concerned in this study than
 in the laboratory. It is hoped that the study
 which of the data obtained in this study would show to
 be made in a laboratory, but that was in 1920.
 The hope of this paper is that it will be of use
 to the study in a laboratory which is shown in the
 appendix.
 The writer is grateful to Professor John D.
 Latham for his advice and general direction of the
 research. Mr. John D. Latham was very helpful in the
 design of all the electrical equipment. (Appendix)
 It is hoped that the study will be of great assistance in the design
 and construction of the apparatus and study.

METHODS

The Laval nozzle was made of lucite for two reasons: First, because of its transparency, through lucite it is possible to observe the electrical glow discharge at different Mach numbers and at different static pressures. Second, since lucite is a good insulator, there was no danger of a current flow to ground through the nozzle if a short occurred. Lucite has proved to be an excellent material to satisfy the above requirements.

The probes were designed to be strong enough so that they would not bend in supersonic airflow. Also, a coating of arcylold, which is a liquid plastic that hardens in about 48 hours, was used on each probe not only to give more rigidity but also to act as an insulator. The insulatory properties of the coating were essential, especially where the probes were close together, to avoid arcing downstream of the platinum wire. Care was taken not to coat the plate circuit nor the platinum wire with the liquid plastic. Arcylold proved to be an excellent insulator.

When the plate circuit was positive and the wire negative, measurable current readings were recorded. When the wire was positive and the plate negative, current readings were so small that the electronic equipment designed for these tests did not detect any current flow. Since measurable current readings were recorded when the wire was negative, this type of circuit was used to obtain

The first series was made of single test
reactions. First, because of its frequency, through
which it is possible to observe the electrical wave
change at different load numbers and at different static
pressures. Second, since there is a good example,
there was no need of a separate line in future through
the series if a test occurred. Since the first is an
an example of a test, it is really the same as the
The series was designed to be a very simple
in that they would not be in separate series. Also,
a series of series, which is a single series, is
because in work in series, we need an even test
only to give more rigidity and also to be an example.
The following properties of the series are essential:
extremely small the series with small weight, to
avoid strong connections to the system side. One can
taken not to care the series itself and the system side
with the series itself. Series proved to be an
excellent example.

When the series circuit was tested and the
also tested, necessarily correct results were recorded.
When the line was tested and the series circuit, correct
results were as well as the series circuit.

Assigned for those tests and not about any other line.
Along necessary correct results were recorded when the
also was negative. This type of circuit was used in series

the electrical glow discharge current readings. The theory behind this phenomenon is explained extensively in the paper written by Frank David Werner¹).

The writer has found in this investigation that current readings were obtained up to 350 microamperes at high voltage settings. At these high voltages and currents the electrical glow discharge was almost at an arcing stage; therefore, erratic current readings resulted at this high voltage. For this reason, lower current readings were used in the magnitude of from 60 to 80 microamperes. Enough points were recorded at these lower currents to plot smooth curves as are shown in Figures 2 through 6. From this it can be concluded that the use of lower current will give more stable readings and will give more accurately the trend of events under investigation.

The electronic equipment was designed to give from zero to 10,000 volts positive and from zero to 10,000 volts negative. These two circuits could then be connected in a series to give a range of from zero to 20,000 volts. It was not necessary to use more than 10,000 volts; therefore, it was not necessary to connect the two circuits together. The positive voltage supply was used throughout the entire investigation. The positive lead was connected to the plate circuit which also acted as the static probe while the ground (shield

The electrical and discharge system consists of the theory behind this phenomenon is explained schematically in the paper entitled "The Discharge System".

The water has been in this investigation

that various readings were obtained up to 300 micrometers at high voltage readings. At these high voltages and currents the electrical field discharge was almost at an active stage; therefore, active current readings were obtained at this high voltage. For this reason, lower current readings were used in the magnitude of from 50 to 100 micrometers. These points were recorded at these lower currents to give a more complete picture of the system in figure 2 through 4. From this it can be concluded that the use of lower current will give more stable readings and all data were recorded in the form of a series under investigation.

The electronic equipment was obtained in the form of a 10,000 volt positive and 100,000 volt negative. These two electric fields were connected in a series to give a range of from zero to 20,000 volts. It was not necessary to use zero and 10,000 volts; therefore, it was not necessary to connect the two electric fields. The positive voltage supply was used throughout the entire investigation. The positive lead was connected to the plate directly while the negative lead was connected to the ground (which

of co-ax cable) of the circuit was connected to the probe holding the 0.003-inch platinum wire.

at once revised; all the circuit was composed in the

years ending the 1893-1894 business year.

It was found that the 1893-1894 business year

was the first year in which the business year

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EQUIPMENT

Figure 31 shows the wind tunnel nozzle, the manometer board, the electrical equipment, and the probes. Figure 25 is a drawing, to scale, of the wind tunnel. Figure 26 is a scale drawing of the Laval nozzle blocks. Figures 27, 28, and 29 are diagrams of the electrical equipment.

The wind tunnel was supplied with a continuous flow of dry air from a 225-pound-per-square-inch storage tank of 1750 cubic foot capacity. The high pressure air leaves the tank through a 1-inch high pressure steel pipe. A 1-inch gate valve was used to control the air leaving the high pressure storage tank. The air enters the stagnation chamber of the wind tunnel through a 2-inch pipe. A 2-inch globe valve was installed in the 2-inch pipe line for use as a throttling valve. Stagnation pressures in the stagnation chamber were maintained by adjusting the 2-inch throttling valve.

A total head pressure gage was designed as shown in Figure 25. It consisted of a 1/4-inch steel pipe which held a hypodermic needle. This pipe was placed in the stagnation chamber as shown in the scale drawing of the wind tunnel (Figure 25). One end of this steel tube was plugged while the other end was connected to a pressure gage with a scale from zero to 100 pounds per square inch. It was found that this gage gave pressure readings accurate to within one percent of their correct value.

Figure 27, 28, and 29 are diagrams of the electrical equipment.

The wind tunnel was supplied with a continuous flow of dry air from a 200-pound-per-square-inch storage tank at 1750 cubic feet capacity. The high pressure air leaves the tank through a 1-inch high pressure orifice. A 1-inch side drive was used to operate the six leaving the high pressure storage tank. The air enters the expansion chamber at the inlet through a 2-inch pipe. A 2-inch side drive was installed in the 2-inch pipe. A 2-inch side drive was installed in the 2-inch pipe. A 2-inch side drive was installed in the 2-inch pipe. A 2-inch side drive was installed in the 2-inch pipe.

which is shown in Figure 22. It consisted of a 1/4-inch steel plate which held a hypodermic needle. This plate was placed in the translation chamber as shown in the section drawing of the main frame (Figure 23). One end of this plate was plugged with the other end was connected to a hypodermic pipe with a screw from left to right. The pipe was 1/4 inch in diameter. It was found that this pipe gave the best results. It was found that this pipe gave the best results.

A standard type mercury manometer was constructed and used throughout this investigation to measure static pressure. Figure 31 shows this manometer as it was used to measure static pressures.

Figure 25 shows the bell-mouth entrance to the nozzle. This bell-mouth, made of hydrostone, proved to be very satisfactory. No cracking or chipping of the bell-mouth was noticed at the completion of this investigation.

Figure 26 is a scale drawing of the Laval nozzle blocks. The blocks and side plates were made of lucite and were designed to give a Mach number from 1.0 to 3.0, but a manufacturing error was made which gave a slightly different Mach number. This difference is shown in Figure 1. It can also be seen in Figure 1 that the experimental Mach numbers are slightly less than the theoretical Mach numbers at the same positions in the nozzle, but still gave satisfactory Mach numbers for $M = 1.0$ to $M = 3.1$.

The probes, as shown in Figures 30 and 33, were made of 1/4-inch steel tubing. The static probe also acted as the plate of the circuit. A 1/16-inch brass tube was inserted in the upstream end of the static probe. A static hole was drilled in this brass tube 8 diameters from the upstream end. The upstream end of the 1/16-inch brass tube was closed by silver solder and ground to a very fine point. A 1/16-inch solid steel rod was inserted in the upstream end of the glow probe that held the

platinum wire. This upstream end of the solid steel rod was also ground to a very fine point. The 0.003-inch platinum wire was soldered to the upstream sharp end of the steel rod.

Both probes were coated with arcyloid which is a liquid plastic that hardens in about 48 hours. These probes were mounted in lucite holders that were fastened to the probe support. The probe support could be moved back and forth on a steel track, thus enabling the probes to be set at any position desired in the nozzle. Figure 32 shows the probe support and the track on which it could be moved.

The electronic equipment was designed in two separate parts. The circuit for part one is shown in Figure 28. This circuit produced a negative voltage of from zero to 10,000 volts. The circuit for part two is shown in Figure 29. This second circuit produced a positive voltage of from zero to 10,000 volts. Voltmeter and ammeter circuits (Direct Current) were designed as shown and were used to measure currents in microamperes and voltages. All voltmeter and ammeter readings are accurate to within 5 percent of their actual value. Both circuits were installed in the same panel as shown in Figure 31.

platinum wire. This specimen was of the same size and was also ground to a very fine point. The 0.002-inch platinum wire was adjusted to the specimen about one of the steel rods.

Both probes were coated with a special oil which is a liquid plastic that remains in place as hard. These probes were mounted in inside holders that were fastened to the probe support. The probe support could be moved back and forth on a steel track, thus enabling the probes to be set at any position desired in the specimen. Figure 22 shows the probe support and the track on which it could be moved.

The electric circuit was designed in two separate parts. The circuit for part one is shown in Figure 23. This circuit produced a negative voltage of from zero to 10,000 volts. The circuit for part two is shown in Figure 24. This second circuit produced a positive voltage of from zero to 10,000 volts. Voltages and current densities (microamp/cm²) were designed as shown and were used to obtain curves in micrographs and voltages. All voltages and current readings are accurate to within 10 percent of their actual values. Both circuits were included in the same panel as shown in Figure 25.

TEST PROCEDURE

The static probe, which also acted as the plate circuit of the electrical glow discharge, was inserted in the nozzle at 0.71-inch from the throat with the static hole just opposite the 0.71-inch position. At this position in the nozzle runs were made for different Mach numbers. The stagnation pressure was changed through a range of values to determine the stagnation pressure that produced the approximate theoretical Mach number in the nozzle at the 0.71-inch position. At positions of 1-inch, 2, 3, and 4 inches downstream the same procedure as described above was followed. A curve of the results is shown in Figure 1.

It was found that stagnation pressures of 25, 30, and 40 pounds per square inch gage gave a Mach number of 2.08 at the 1-inch position. Stagnation pressures of 40, 50, and 60 pounds per square inch gage gave a Mach number of 2.44 at the 2-inch position. The 3 and 4-inch positions were probed in the same manner, and Mach numbers of 2.8 and 3.1 were established. Stagnation pressures of 70, 80, and 90 pounds per square inch gage were used at the 3-inch position, and 90, 94, and 100 pounds per square inch were used at the 4-inch position. It was found that below certain stagnation pressures the Mach number at any position could not be obtained. Since the nozzle did not have a diffuser attached to its exit, these high stagnation pressures are to be expected and check very

THE RESULTS

The static force, which also acted as the force of the electrical field, was inserted in the nozzle at 0.75-inch from the nozzle with the static force just opposite the 0.75-inch position. At this position in the nozzle were made the different measurements. The electrical pressure was changed through a range of values to determine the electrical pressure that produced the approximate theoretical maximum velocity in the nozzle at the 0.75-inch position. At positions of 1-inch, 2, 3, and 4 inches downstream the same procedure was followed above and below. A series of the results is shown in figure 1.

It was found that satisfactory velocities of 20, 30, and 40 pounds per square inch were made with a static force of 2.00 at the 1-inch position. Satisfactory velocities of 20, 30, and 40 pounds per square inch were made with a static force of 2.44 at the 2-inch position. The 3 and 4-inch positions were studied in the same manner, and satisfactory velocities of 2.8 and 3.1 were obtained. Satisfactory velocities of 20, 30, and 40 pounds per square inch were made at the 5-inch position, and 30, 35, and 40 pounds per square inch were used at the 6-inch position. It was found that below certain static pressure pressures the static force at any position could not be obtained. Since the nozzle did not have a diameter attached to its exit, these high static pressure pressures are to be expected and about 200

closely to those given in reference 5.

After the static probe Mach number calibration (Figure 1) was made at the various positions in the nozzle, the probe that held the small platinum wire was placed in position. The 0.003-inch platinum wire on this probe was lined up just opposite the static hole in the static probe. With the wire and plate at 0.25-inch spacing between them inserted in the nozzle at the various positions, runs were made as described in the preceding paragraph. Using this configuration, it was found that the same static pressures as obtained with the static probe alone were obtained at any position using corresponding stagnation pressures, thus showing no effect of the glow probe on static pressure and Mach number at locations under investigation.

With the probe spacing of 0.25-inch and the stagnation pressures necessary to produce the Mach number at any given position, runs were made at the various positions in the tunnel. The same procedure was followed for a 0.125-inch spacing. Ammeter and voltmeter readings were recorded during each run.

Since runs were made as rapidly as possible, it was assumed that for any run the temperature remained constant. Also, dry air (-400 F.) was used throughout the investigation.

A vacuum jar was used to determine pressure effect on the glow discharge at zero Mach number. The

closely to those given in statement D.

After the static probe was moved following

(Figure 1) was once at the various positions in the

circle, the probe was held in the same position and

placed in position. The 0.005-inch distance was on this

probe was lined up just opposite the static probe in the

static probe. With the wire and pins at 0.005-inch

spacing between them located in the circle at the various

positions, some were as described in the preceding

paragraph. Using this method, it was found that

the same static pressure is obtained with the static

probe alone was obtained at any position with the static

the static pressure, some were as shown in Figure 1.

Five probe on static pressure was each shown at various

static pressure.

With the probe spacing of 0.005-inch and the

static pressure pressure was shown in Figure 1.

At any given position, some were as shown in Figure 1.

positions in the circle. The same pressure was obtained

for a 0.005-inch spacing. Another and different results

was recorded using zero gap.

Static pressure was as shown in Figure 1.

was shown that for any one the static pressure was

constant. Also, the static pressure was as shown in Figure 1.

the investigation.

A system of static pressure

shown in the static pressure at zero gap position. The

plate and wire used in the vacuum jar were made of the same material and were the same size. Various absolute pressures were maintained in the jar, and ammeter and voltmeter readings were obtained. Dry air, often ventilated to avoid ionization, was used in the vacuum jar. Figure 2 gives data obtained from this test.

glass and also used in the various jar also made of tin
 when material and were the same size. Various designs
 sometimes were retained in the jar, but usually the
 designs were retained in the jar, but after the jar
 to some extent, and used in the various jar. These
 glass were retained from this jar.

TEST DATA (EXPLANATION OF)

Figure 1 shows the Mach number versus the distance along the nozzle. The Mach number was determined by a static probe connected to a mercury manometer. The stagnation pressure was read directly from a pressure gage. If the stagnation pressure, the static pressure, and the barometer reading are known, Mach number can be easily determined. Isentropic flow was assumed upstream and downstream (but not through) the normal shock wave.

Figures 1 through 7 give microamperes versus volts at various Mach numbers ranging from zero to 3.1. The space between the plate and the wire was 0.25-inch. These curves show that the glow discharge is definitely dependent on pressure.

Figures 8 through 12 give absolute pressures versus volts at various current flows. The data for these curves were obtained from the microamperes versus volts curves (Figures 1-7).

The final curve, Figure 13, shows the effect of Mach number. Here microamperes versus volts at constant absolute pressure were plotted. After studying these curves, it can be readily seen that the glow discharge is velocity dependent. It can be seen that all curves from $M = \text{zero}$ to $M = 2.8$ have the same general trend, but the $M = 3.1$ curve is different. This is probably due to experimental errors and to poor supersonic airflow at the 4-inch position. Nevertheless, all the

curves show the same general trends and indicate that the Mach number has an effect on the electrical glow discharge.

The remaining curves, Figures 13 through 24, show test data under the same condition as above except that the spacing of the plate and wire was reduced to 0.125-inch. Again it can be seen that the electrical glow discharge is pressure and Mach number dependent. However, this time the Mach number curves did not plot in the same sequence. This is partly due to experimental errors, and it is expected that at the 0.125-inch spacing there is some airflow interference between the plate and the wire, even though it did not show up on the static readings. These curves, even though they don't follow in sequence, show a general trend which indicated that the glow discharge is dependent on Mach number.

Figure 34 shows a spark photograph of the nozzle blocks at a Mach number of zero. It can be seen that the channel walls are fogged up; this is due to poor glueing of the side plates to the nozzle blocks, indicating that the glue had run down the walls of the nozzle. The black heavy line below the channel is a tape measuring device for placing probes at exact position in the nozzle.

Figure 35 shows the same nozzle with supersonic airflow at a Mach number of 2.81. Shock waves at the 4-inch position can be seen. Also, at about the 4-inch position the flow starts to separate, and by the time it

either end of the same general form and indicate that

the same number has an effect on the electrical glow

discharge.

The two large series, which is shown in

then last, under the same conditions as above except

that the spacing of the plates and wire was reduced to

0.125-inch. Again it can be seen that the electrical

glow discharge is prominent and much more prominent.

However, this time the glow is much more intense and

in the same direction. This is partly due to experimental

errors, and it is expected that at the 0.125-inch spacing

there is some slight interference between the plates and

the wire, even though it is not one of the walls

residual. These factors, even though they are of little

in importance, show a general trend which indicates that

the glow discharge is dependent on these factors.

Figure 10 shows a series of photographs of the discharge

glow at a fixed number of series. It can be seen that the

discharge is very bright and that it is due to the glow

of the wire and the plates, indicating that

the glow is due to the wire and the plates. The glow

is very bright and the discharge is a very interesting

for glowing gases at various positions in the series.

Figure 11 shows the same series with a different

spacing of the plates and wire. Again it can be seen that

the glow is very bright and that it is due to the glow

of the wire and the plates. The glow is very bright and

reaches the end of the nozzle it appears to have separated almost completely. Due to the cloudy sides of the channel nothing else can be seen.

Figure 36 shows the same nozzle block with supersonic airflow at a Mach number of 2.81, but this time the probes are inserted in the nozzle. The spacing between the plate and wire was 0.25-inch. Here it appears that the probes have helped the flow, but again due to reflection through the top wall of the channel and cloudy channel walls, little of importance can be seen. Even though the flow appears better with the probes inserted, the static probe manometer readings indicated that ^{at} the 4-inch position separation and turbulent flow exists.

Since this experimentation was the first exploration of the supersonic flow by means of sharp point glow discharge, the establishment of methods, trends, limitations, and possible expectations for this type of flow study was more important than finality of results. At the start of the investigation it was not possible to predict in which direction to concentrate and, therefore, a flexibility in general of instrumentation was more important than fine accuracy of any one item in particular, but even with this procedure, the accuracy of all test data is limited only by the type of instrumentation used and the accuracy with which it was read. Considering the type of gages and electronic equipment used, an overall

position the end of the nozzle is placed as near as possible to the nozzle. Use the steady flow of the liquid to the nozzle and be sure.

Figure 50 shows the new nozzle with

nozzle at a distance of 2.0 ft. from the

the nozzle was located in the nozzle. The nozzle

shows the plate was 2.0 ft. from the

shows that the nozzle was 2.0 ft. from the

the nozzle was 2.0 ft. from the

shows the nozzle was 2.0 ft. from the

shows the nozzle was 2.0 ft. from the

shows the nozzle was 2.0 ft. from the

shows the nozzle was 2.0 ft. from the

shows

shows the nozzle was 2.0 ft. from the

shows the nozzle was 2.0 ft. from the

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shows the nozzle was 2.0 ft. from the

shows the nozzle was 2.0 ft. from the

shows the nozzle was 2.0 ft. from the

shows the nozzle was 2.0 ft. from the

shows the nozzle was 2.0 ft. from the

accuracy of all test data is approximately 95 percent.

Account of all last year is approximately as follows.

The first part of the year was very dry and hot.

The second part of the year was very wet and cold.

The third part of the year was very dry and hot.

The fourth part of the year was very wet and cold.

The fifth part of the year was very dry and hot.

The sixth part of the year was very wet and cold.

The seventh part of the year was very dry and hot.

The eighth part of the year was very wet and cold.

The ninth part of the year was very dry and hot.

The tenth part of the year was very wet and cold.

The eleventh part of the year was very dry and hot.

The twelfth part of the year was very wet and cold.

The thirteenth part of the year was very dry and hot.

The fourteenth part of the year was very wet and cold.

The fifteenth part of the year was very dry and hot.

The sixteenth part of the year was very wet and cold.

The seventeenth part of the year was very dry and hot.

The eighteenth part of the year was very wet and cold.

The nineteenth part of the year was very dry and hot.

The twentieth part of the year was very wet and cold.

The twenty-first part of the year was very dry and hot.

The twenty-second part of the year was very wet and cold.

The twenty-third part of the year was very dry and hot.

CONCLUSIONS AND RECOMMENDATIONS

It is concluded that an electrical glow discharge when inserted in supersonic airflow has the following characteristics:

1. The glow current is definitely pressure sensitive.
2. The glow current is dependent on velocity -- that is, any Mach number between $M = 1$ and $M = 3$ change effects the glow current.
3. A greater voltage is required to maintain a given current for larger electrode spacings, a larger size wire, and positive wire polarities.
4. Platinum wire 0.003-inch diameter could be used in this investigation because any smaller size wire bent when it was inserted in supersonic airflow.
5. Current flow from 10 to 80 microamperes gives enough glow discharge for this experiment.
6. The shape of the plate and the material from which it is made effect the current flow.
7. The glow changes in size with changes in Mach number.
8. The glow changes in size with change in static pressure.
9. This device adapts itself for use as a static pressure measuring instrument and possibly as a Mach number recorder.

The following recommendations are given below:

1. If lucite nozzle blocks are to be made for this tunnel, it is recommended that great care be taken in the glueing process to give clear and smooth walls.
2. Nozzle blocks should be made by the method of characteristics, thus eliminating the bad flow conditions encountered in the Laval nozzle.

LOCATIONS AND RECOMMENDATIONS

It is recommended that an additional flow rate

be added when located in appropriate areas and

following recommendations:

1. The flow pattern is relatively pressure sensitive.
2. The flow pattern is dependent on velocity. The flow is very much affected by the velocity of the flow.
3. A higher velocity is required to maintain a flow pattern for larger diameter pipes, a larger flow rate, and positive flow pattern.
4. The flow rate is 0.003-inch diameter must be used in this location because the velocity is the same as it was located in upstream.
5. The flow rate is 10 to 20 micrometers flow rate for this location.
6. The shape of the pipe and the velocity flow is most affected the overall flow.
7. The flow pattern is also affected in some cases.
8. The flow changes in flow rate change in flow rate.
9. This flow rate is likely to be a static pressure reading (pressure) and possibly a flow rate reading.

The following recommendations are given below:

1. If the flow rate is 10 to 20 micrometers flow rate, it is recommended that flow rate be added in the flow rate to flow rate and flow rate.
2. The flow rate is 10 to 20 micrometers flow rate, it is recommended that flow rate be added in the flow rate to flow rate and flow rate.

3. An extremely sensitive type of throttling valve be incorporated in the equipment to enable the operator to hold stagnation pressures more closely to the desired value.
4. An accurate means of measuring stagnation pressures be used. It is suggested that an electronic gage (strain gage) be used.
5. A mount holder for the probes should be designed so that it will give good accessibility to a change in spacing of plate and wire.
6. The two probes should be made of a strong insulating material, thus eliminating steel tubing and liquid plastic insulations.
7. A high voltage fuse should be used in the electronic equipment to avoid any voltage leakage and to protect the power supply.
8. A voltmeter and an ammeter circuit should be designed to measure the voltage and the current when the two power supplies are connected in series.
9. A tapered needle to give sharper point and enough strength to withstand air blast may be necessary and if it is not too expensive to manufacture, should be tried in the next experiments.

3. An electrically sensitive type of photoelectric cell
be incorporated in the equipment to enable the
operator to hold magnetic pressure more closely
in the desired range.
4. An automatic means of measuring magnetic pressure
have no need. It is suggested that an electric
type (strain gauge) be used.
5. A sound indicator for the probe should be designed
so that it will give good sensitivity in a
range of spacing of probe and wire.
6. The two probes should be made of a strong in-
sulating material, thus eliminating steel loading
and rigid plastic insulations.
7. A high voltage time should be used in the
electric equipment to avoid any voltage loss
the wire is broken by the probe supply.
8. A vibrator and an amplifier circuit should be
designed to measure the voltage and the current
from the two probe supplies are connected in
series.
9. A separate switch for five switch point and enough
strength as withstood wire lead and as necessary
and it is not too expensive to manufacture.
should be tried in the next experiments.

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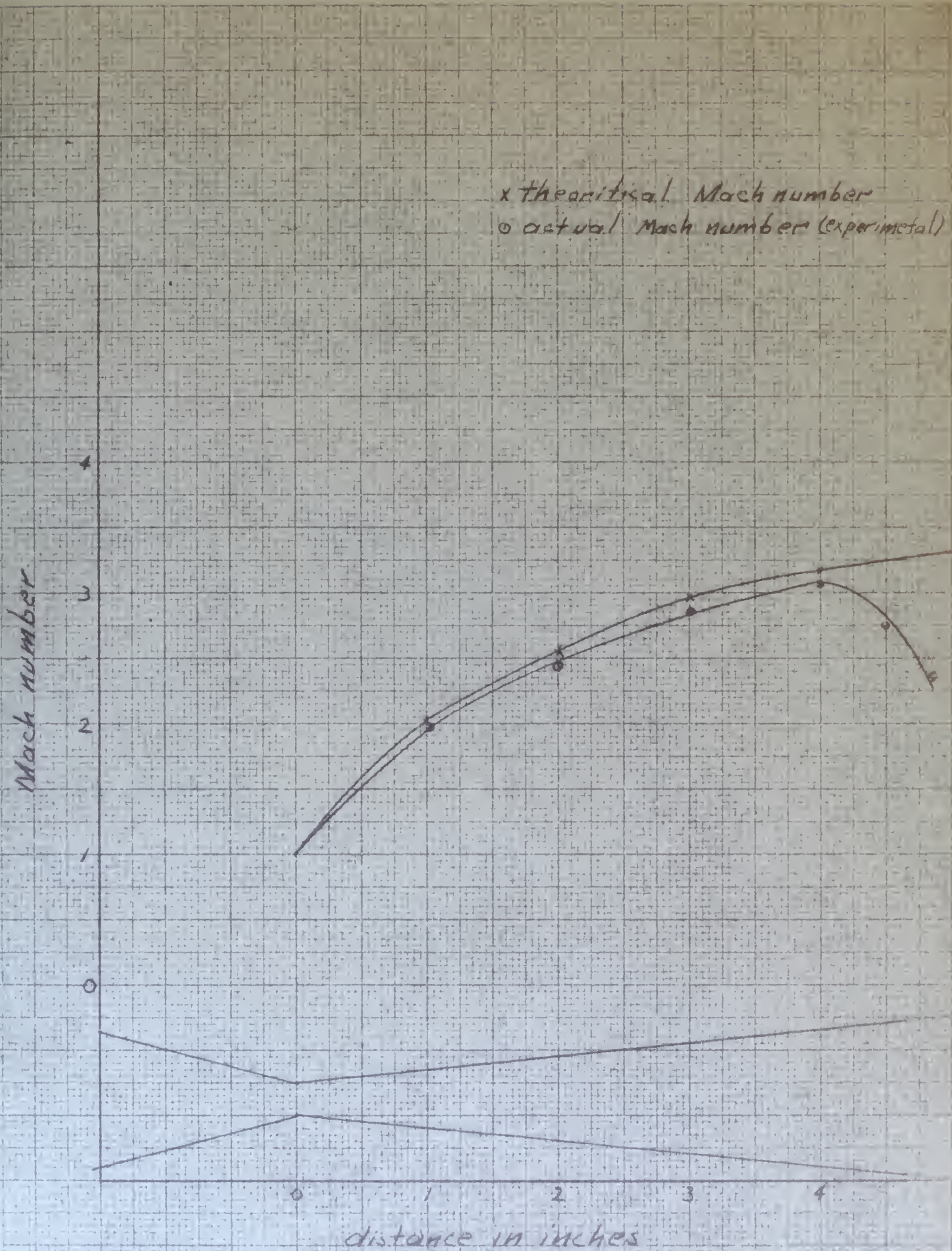


Fig-1-

Voltage VS Current for absolute Pressures
between 29.14 inches Hg and 4.12 inches Hg.

Mach number equal 0

Wire .003 platinum spacing .25 inches

Dry air

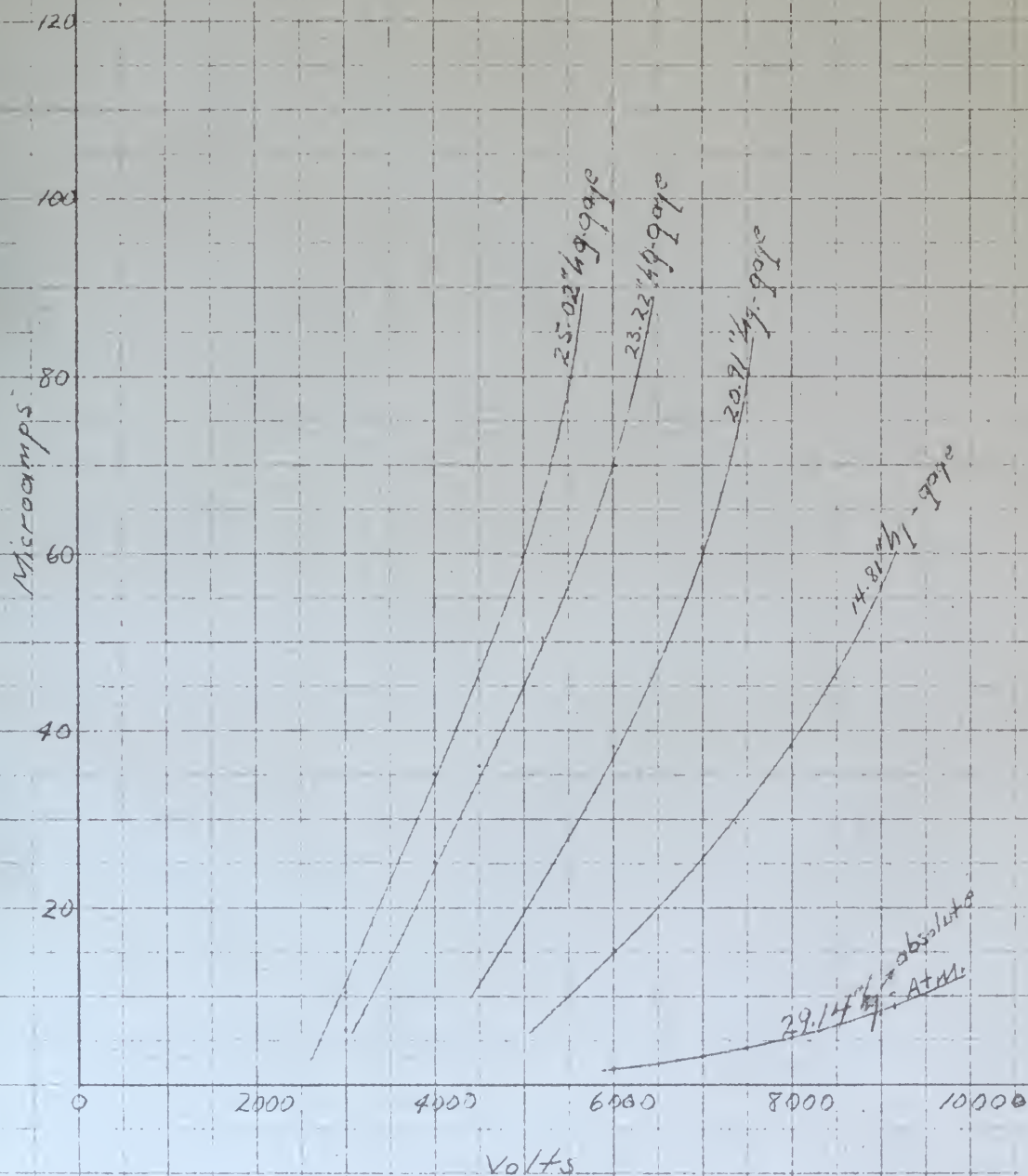


Fig-2 -

Microamps Vs Volts

Wire - .003 spacing .25 inches

Position .71 inches in nozzle

Mach number 1.72

140 Stagnation pressure 21.0 $\frac{\text{lb}}{\text{in}^2}$ abs; static probe 5.4 $\frac{\text{lb}}{\text{in}^2}$ abs
 " " 21.8 $\frac{\text{lb}}{\text{in}^2}$ abs; " 4.3 $\frac{\text{lb}}{\text{in}^2}$ abs
 " " 27.8 $\frac{\text{lb}}{\text{in}^2}$ abs; " 4.2 $\frac{\text{lb}}{\text{in}^2}$ abs

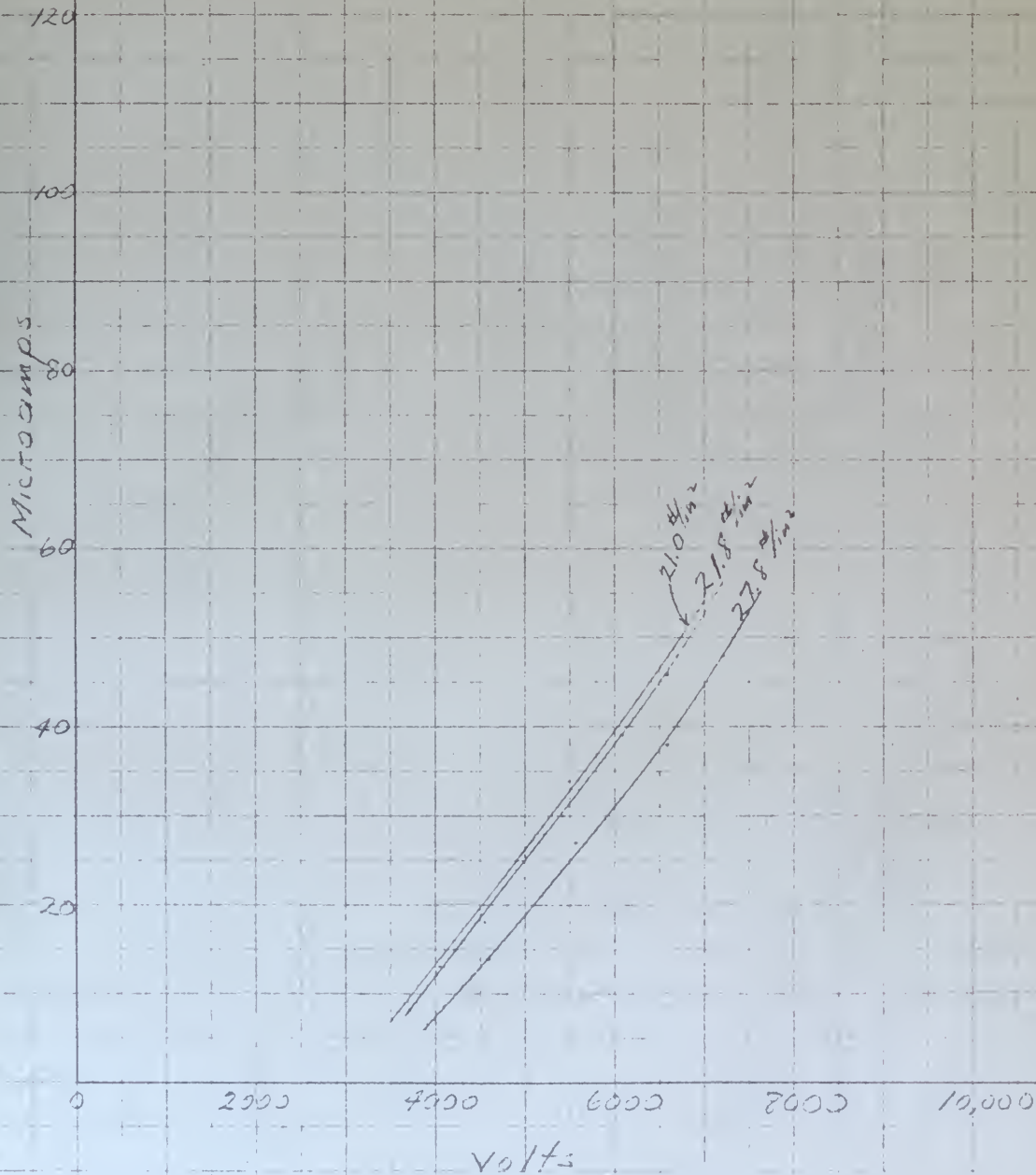


Fig-3-

Microamps vs Volts

.003 wire

.25" spacing

1" position in nozzle

Mach number = 2.08

Stagnation pressure at 25# gage; static probe 10.3 #/sq in
 " " " 30# gage; " " 9.15 #/sq in
 " " " 40# gage; " " 7.15 #/sq in

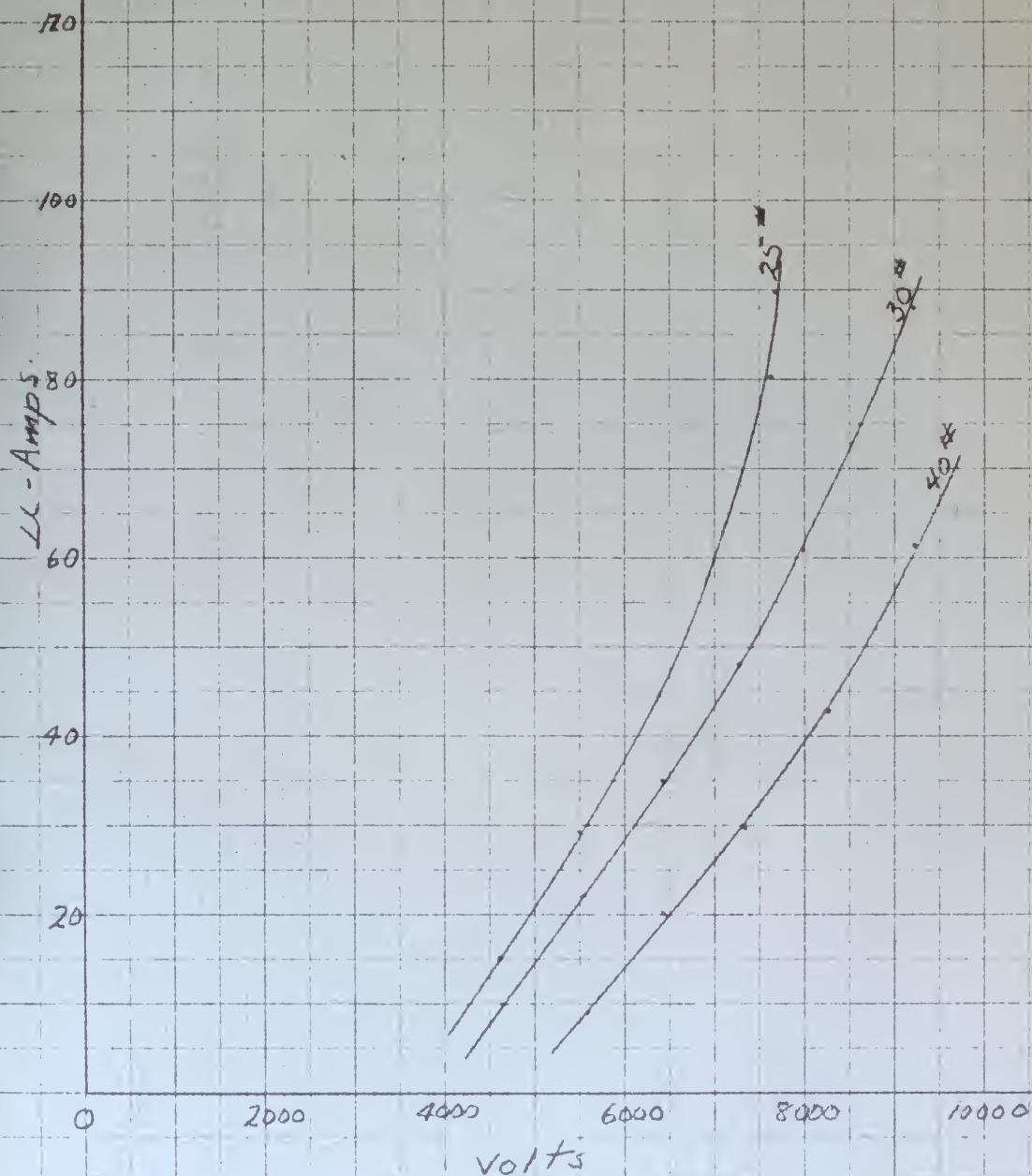


Fig-4-

Microamps Vs Volts

Wire - .003 platinum

Spacing - .25 inches

Position in nozzle 2"

Mach number = 2.49

Stagnation pressure of 40# gage; static probe 11.5# gage

50# gage; " " 10.2# gage

60# gage; " " 9.2# gage

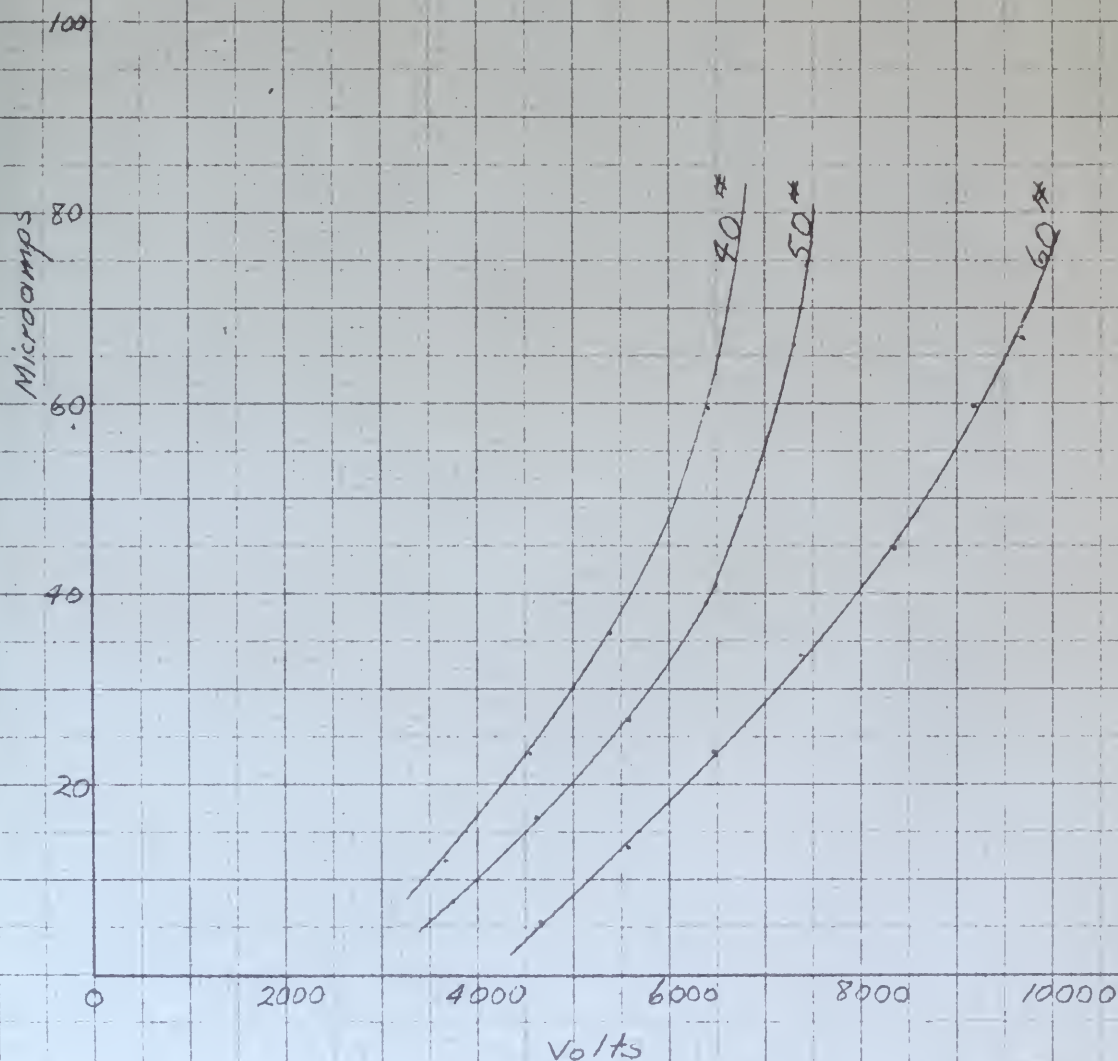


Fig-5-

Microamps vs Volts

Wire - .003 platinum

Spacing .25 inches

Position 3 inches from throat

Mach number 2.81

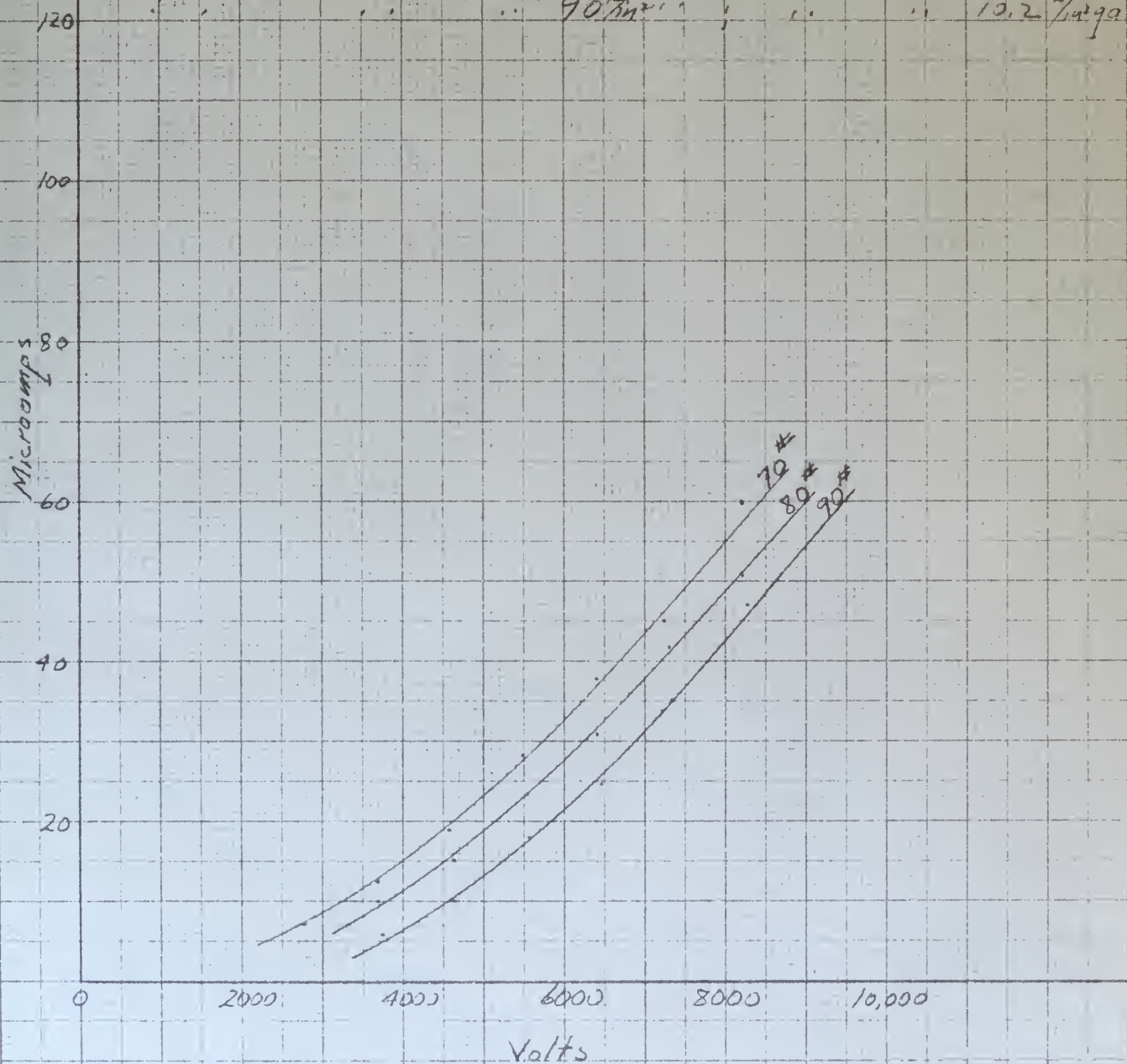
Stagnation pressures of 70th gage; static probe 16.7 #/sq. in.Stagnation pressure of 80th " " " " 16.0 #/sq. in.Stagnation pressure of 90th " " " " 15.2 #/sq. in.

Fig-6-

Microamps vs. Volts

Wire .003 platinum

Spacing .25 inches

Position in nozzle 4"

Mach number = 3.1

Stagnation pressure 90 $\frac{\text{lb}}{\text{in}^2}$ gage ; static probe 12.4 $\frac{\text{lb}}{\text{in}^2}$ gage
" " 94 $\frac{\text{lb}}{\text{in}^2}$ " ; " " 12.1 $\frac{\text{lb}}{\text{in}^2}$ "
" " 100 $\frac{\text{lb}}{\text{in}^2}$ " ; " " 11.87 $\frac{\text{lb}}{\text{in}^2}$ "

Microamps

140

120

100

80

60

40

20

0

2000

4000

6000

8000

10000

Volts

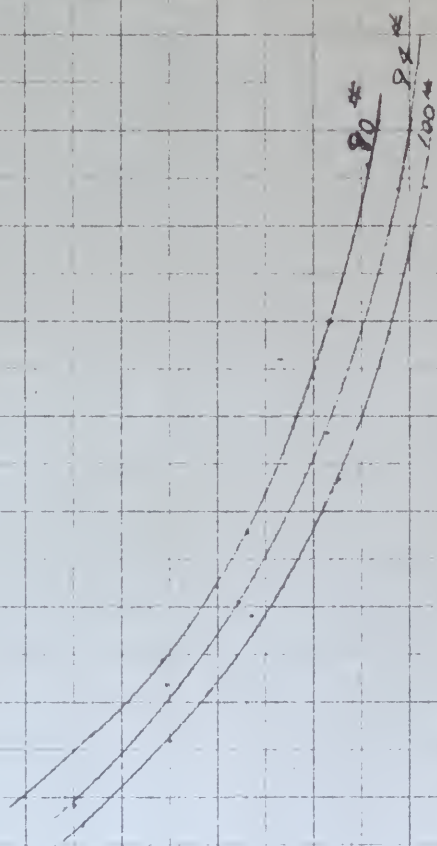


Fig-7-

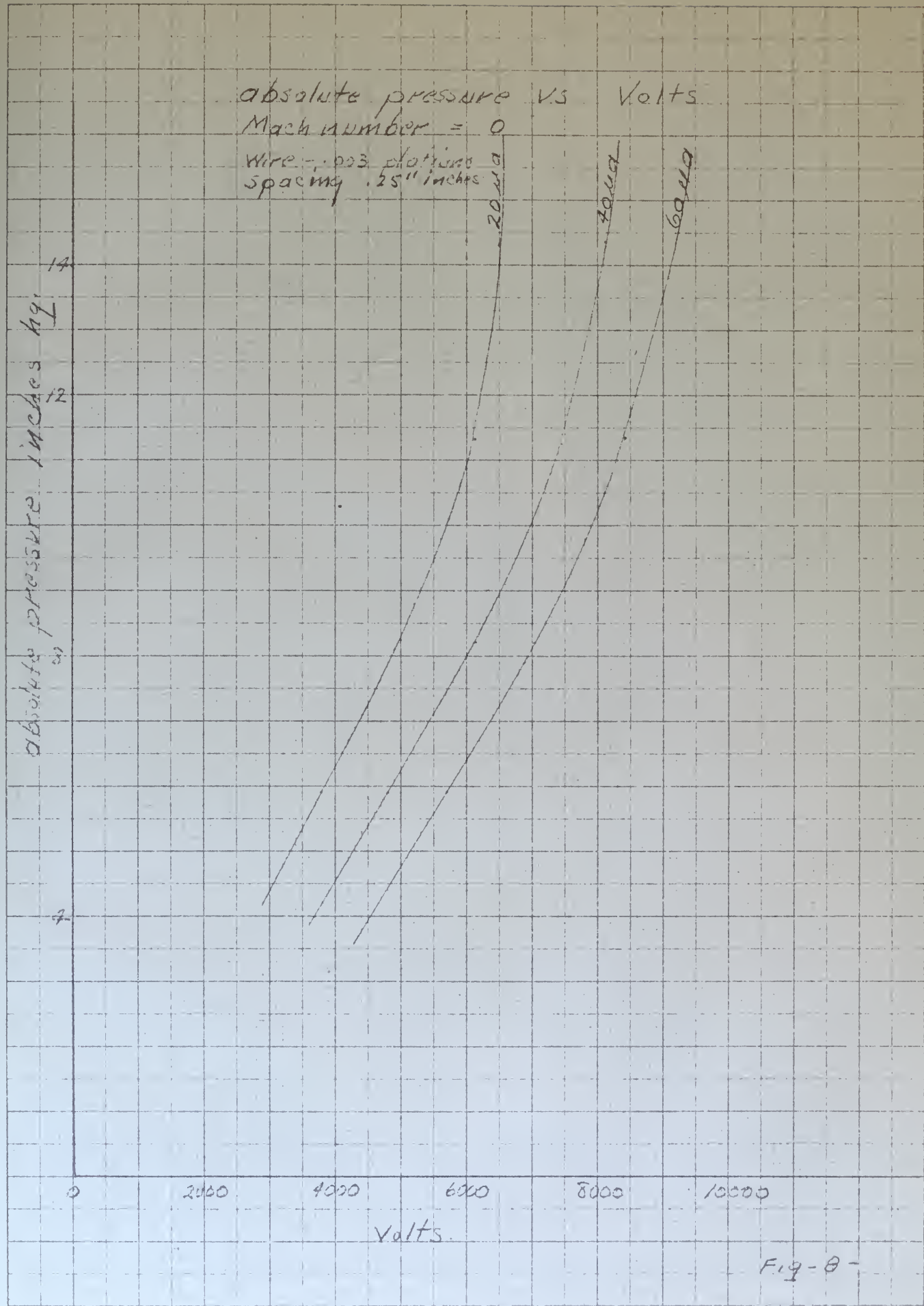


Fig-8-

absolute pressure vs Volts

Mach number = 2.08

Wire = .003 platinum

Spacing = .25 inches

absolute pressure inches Hg

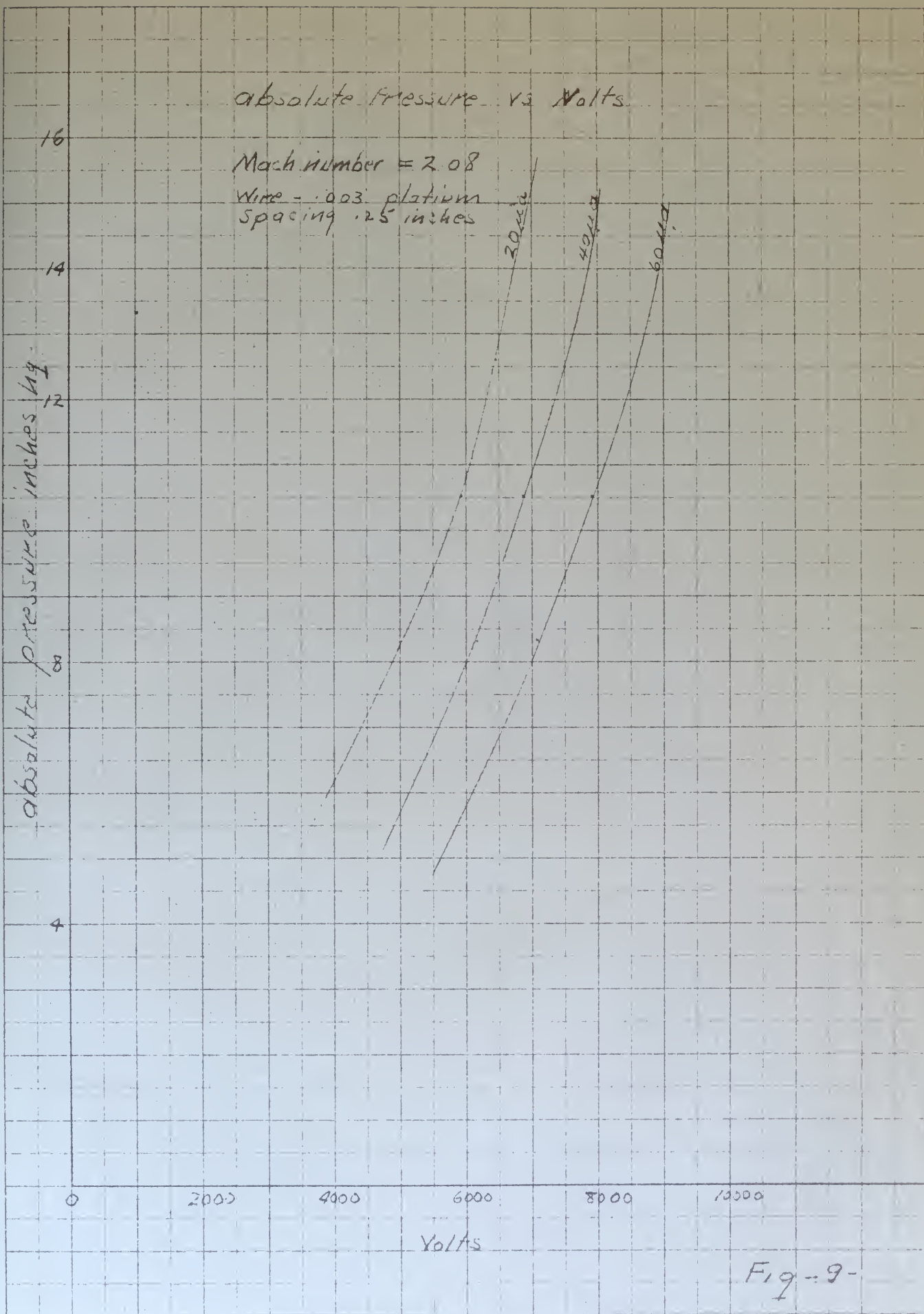
20 Volts

40 Volts

60 Volts

Volts

Fig-9-



absolute pressure vs Volts

Mach number = 2.44

Wire = .003 platinum

Spacing .25 inches

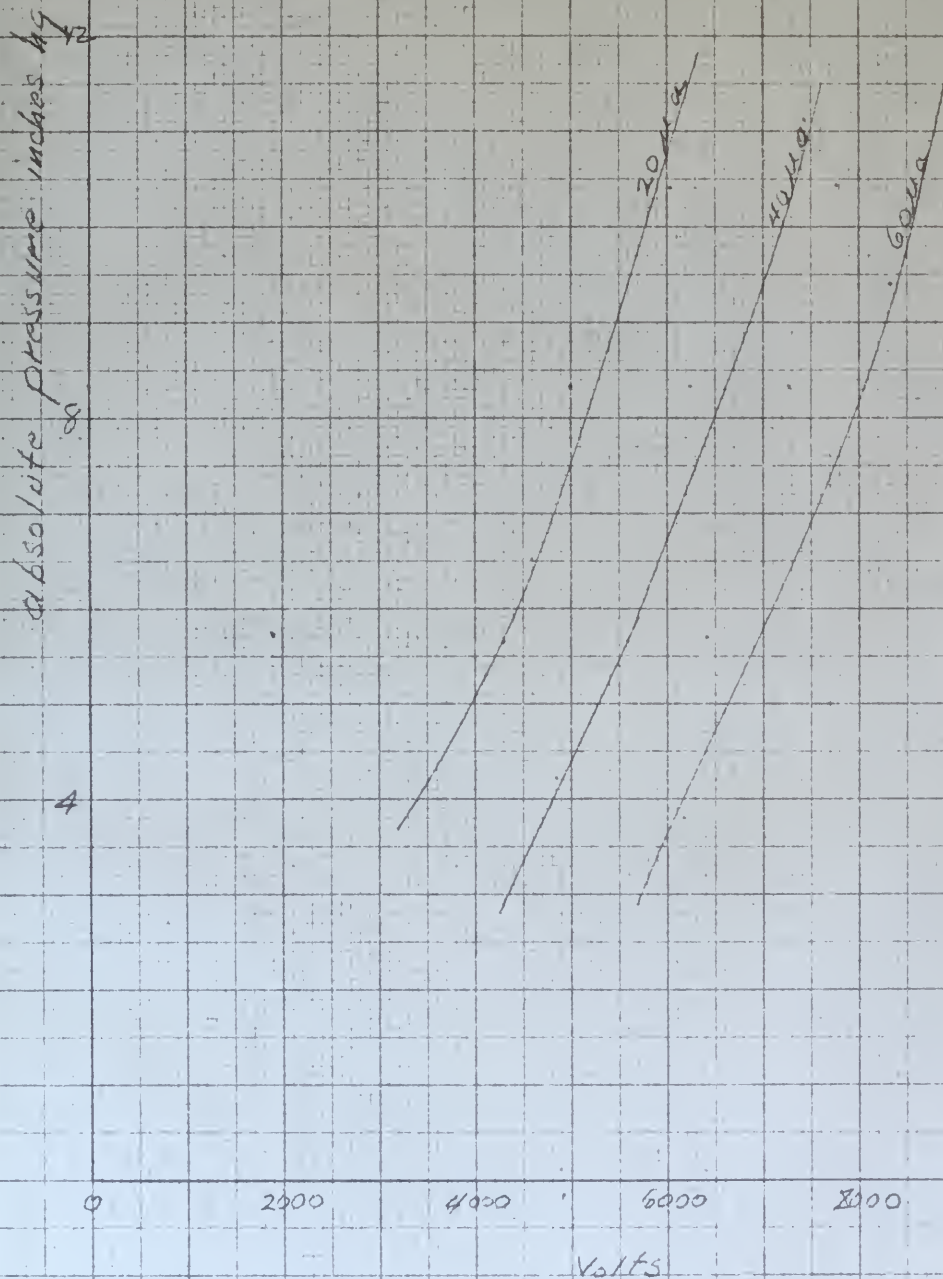


Fig-10-

Absolute Pressure vs Volts

Mach number 2.81

Wire .002 platinum

Spacing .25 inches

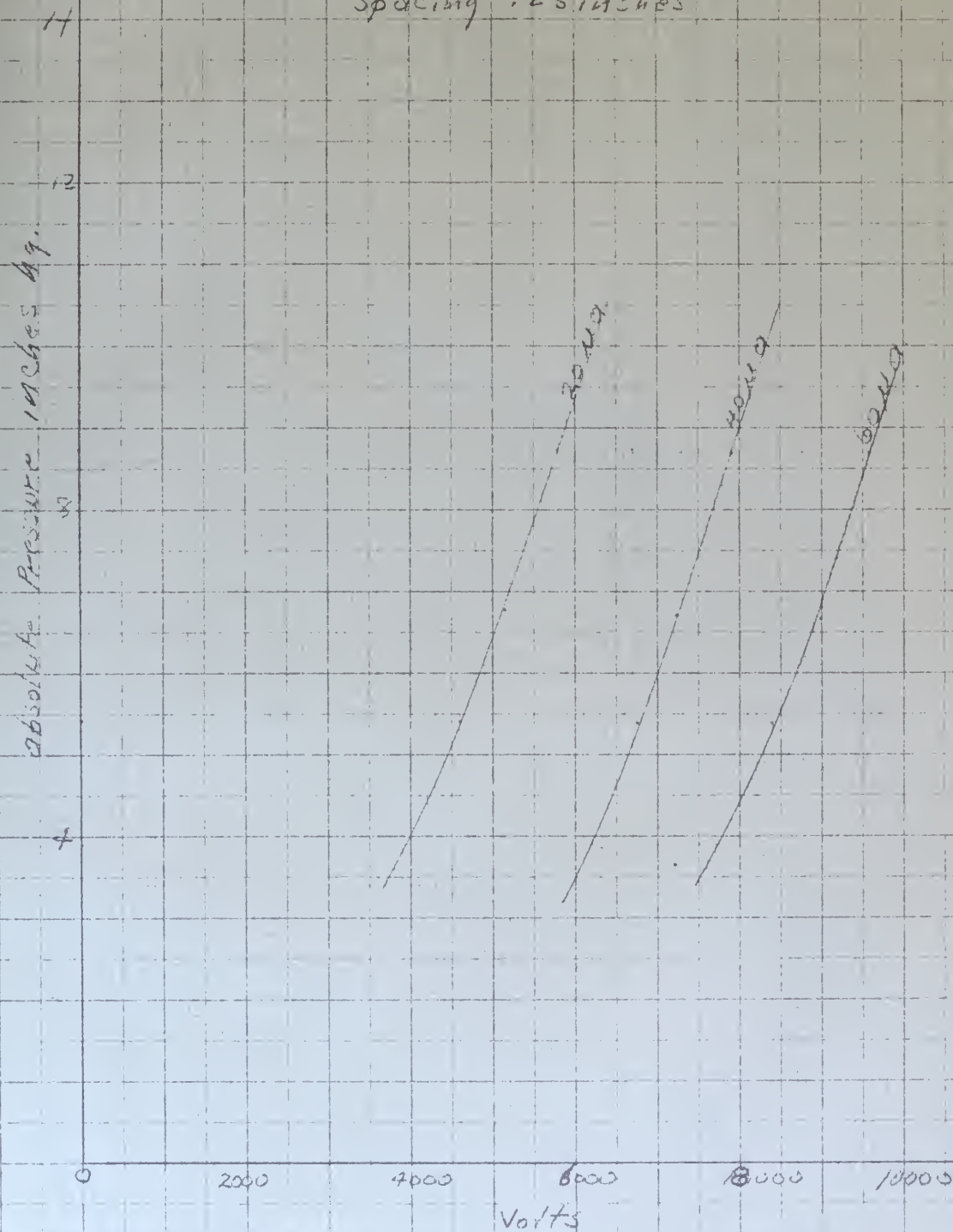


Fig-11-

absolute pressure vs Volts
 Mesh number 3.1
 Wire .003 platinum
 Spacing .25 inches

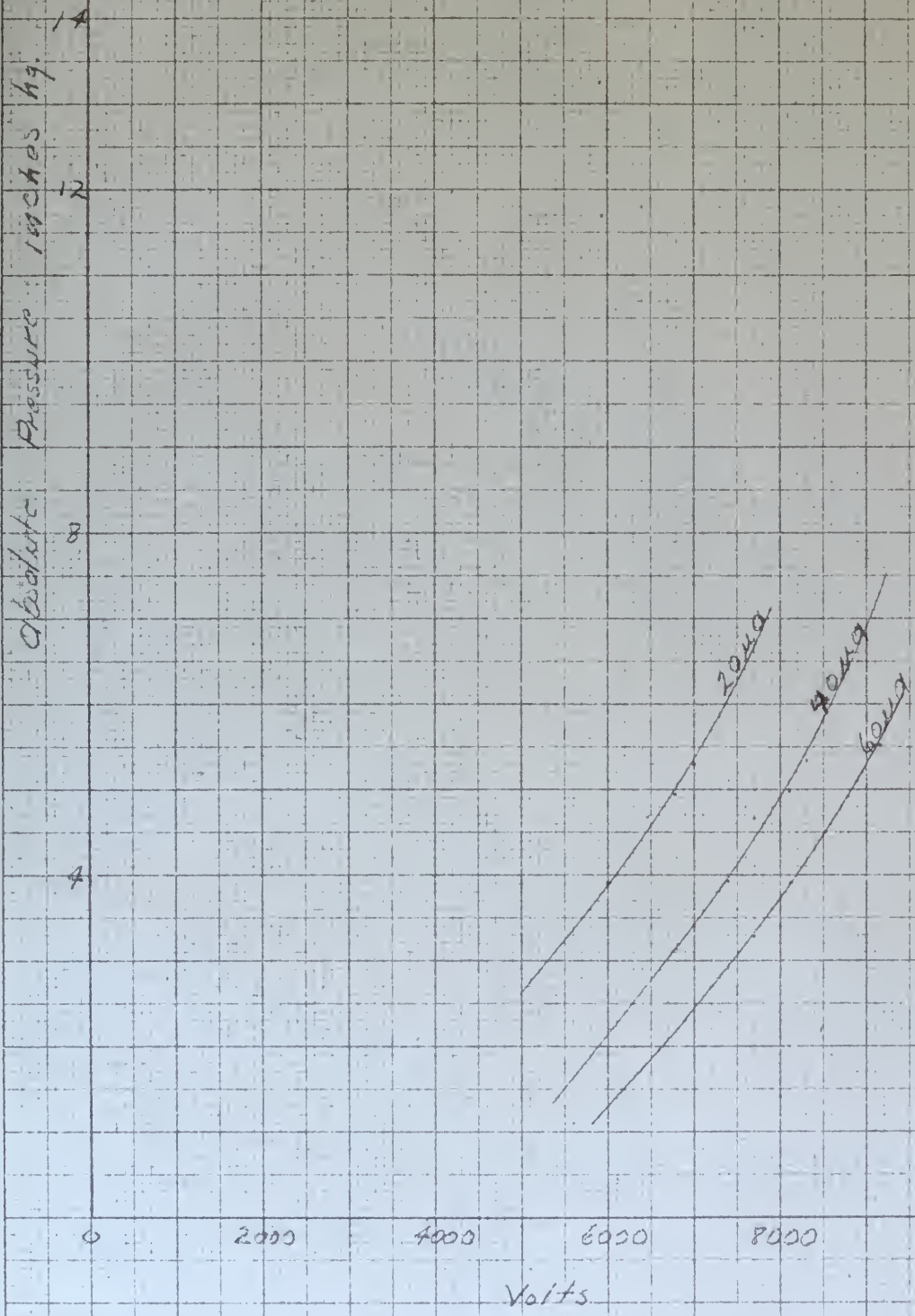


Fig-12-

Microamps vs. Volts at const. obs. Pressure
absolute pressure = 5 inches hg.

Wire - .003 platinum

Spacing - .25 inches

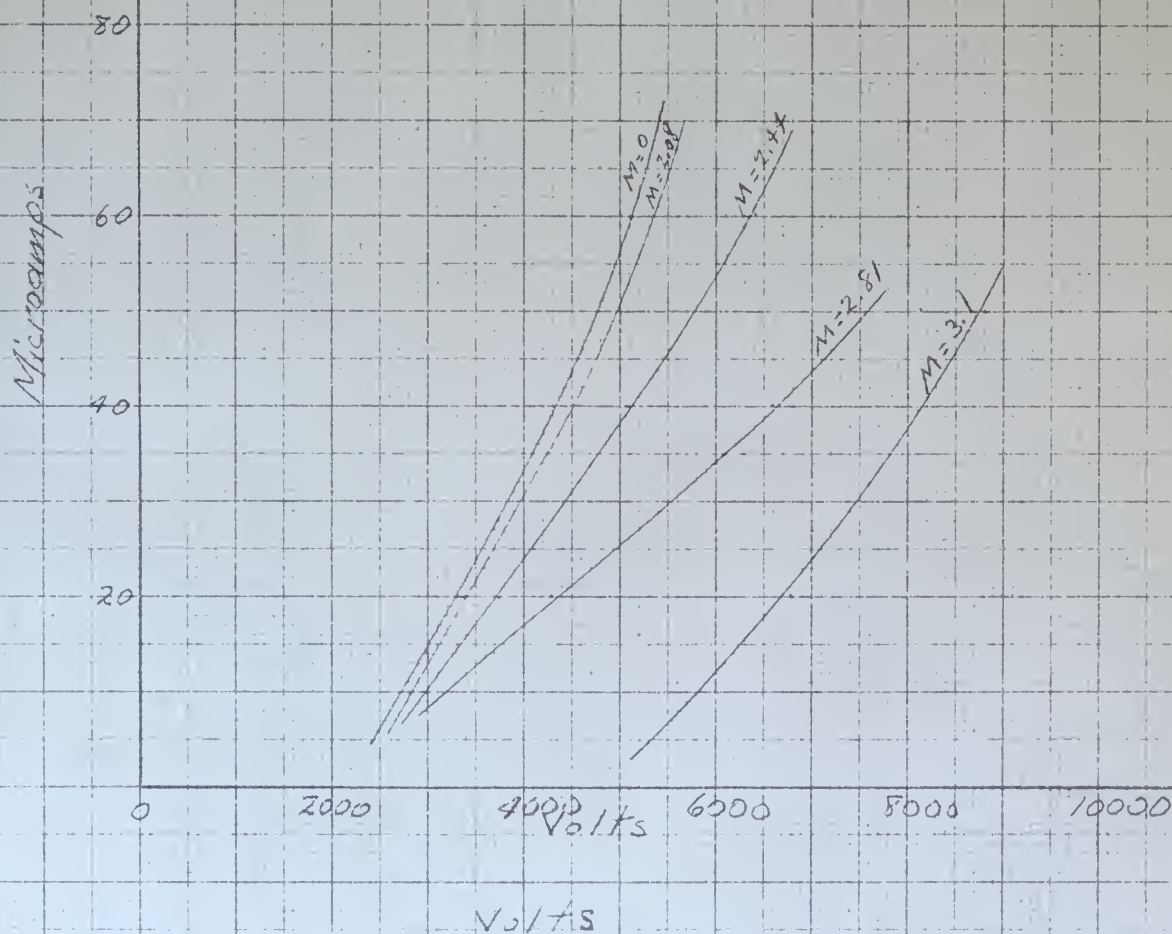


Fig-13-

Voltage vs Current for absolute pressures
between 29.14 inches Hg and 4.46 inches Hg.

Mark number equal 0

Wire .003 platinum ; spacing .125 inches

Dry air

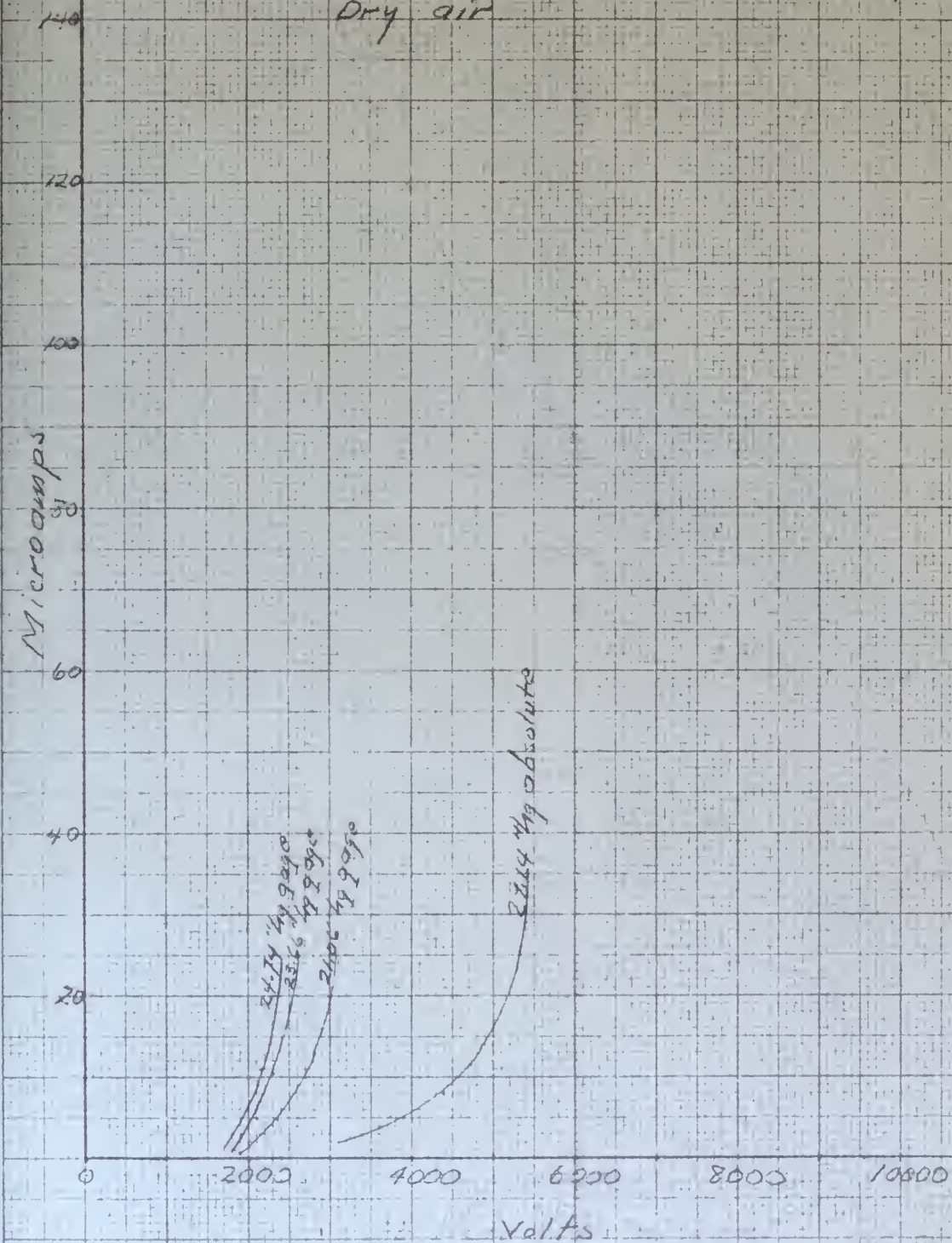


Fig - 1.4 -

Microamps vs Volts

Wire .003 platinum spacing .125"

Position .6 inches in nozzle

Mach number 1.62

Stagnation pressure	21.9 #/in ² abs	Static probe	4.94 #/in ² abs
"	21.2 #/in ² abs	"	4.88 #/in ² abs
"	26.2 #/in ² abs	"	6.51 #/in ² abs

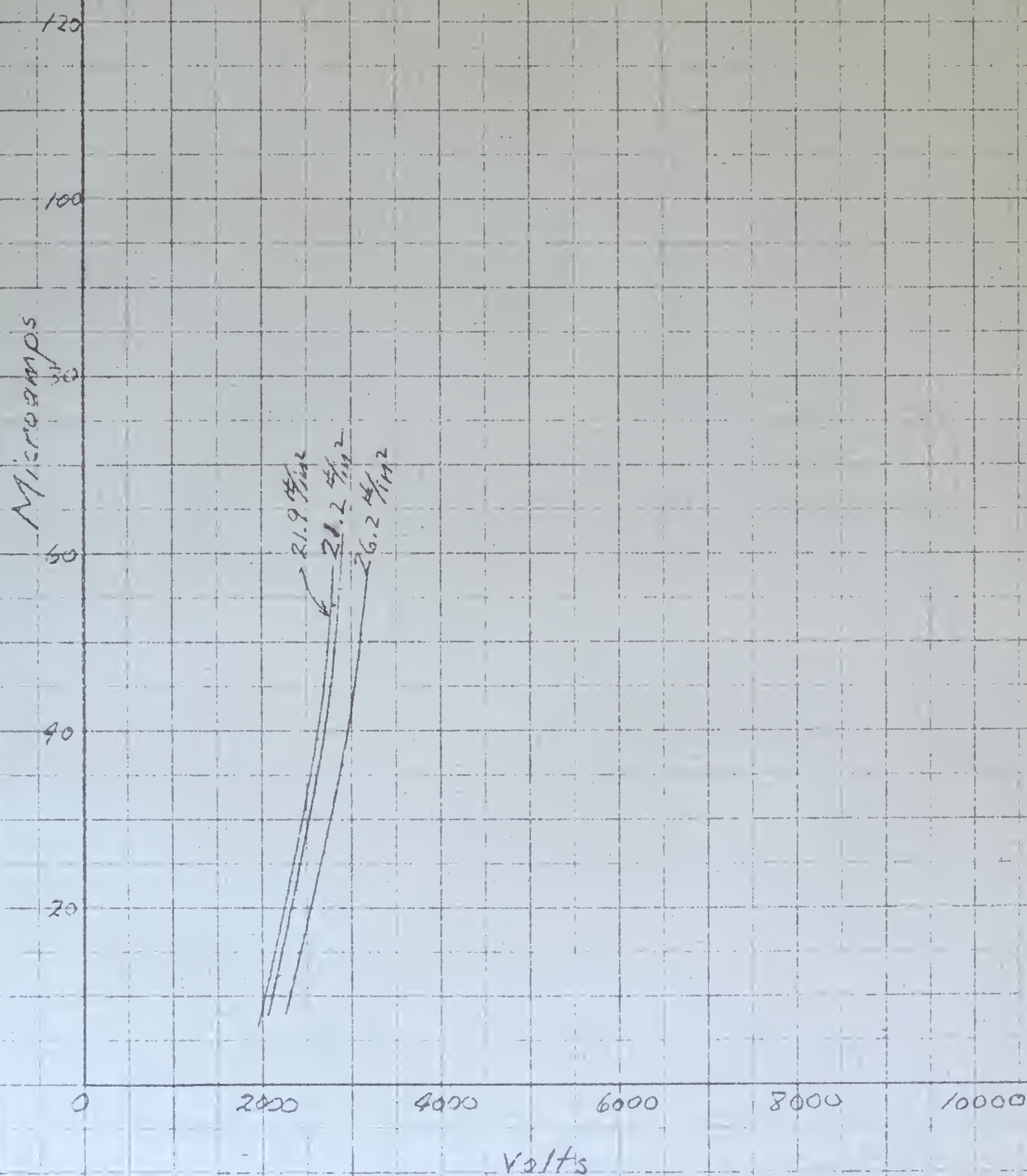


Fig-15-

Microamps VS Volts

Wire .003 platinum

spacing .125"

Position in nozzle 1"

Mach number - 2.03

Stagnation pressure at 25 $\frac{\text{lb}}{\text{in}^2}$ gage; probe (static) 10.3 $\frac{\text{lb}}{\text{in}^2}$
 " 30 $\frac{\text{lb}}{\text{in}^2}$ " " " 1.15 $\frac{\text{lb}}{\text{in}^2}$
 " 40 $\frac{\text{lb}}{\text{in}^2}$ " " " 7.15 $\frac{\text{lb}}{\text{in}^2}$

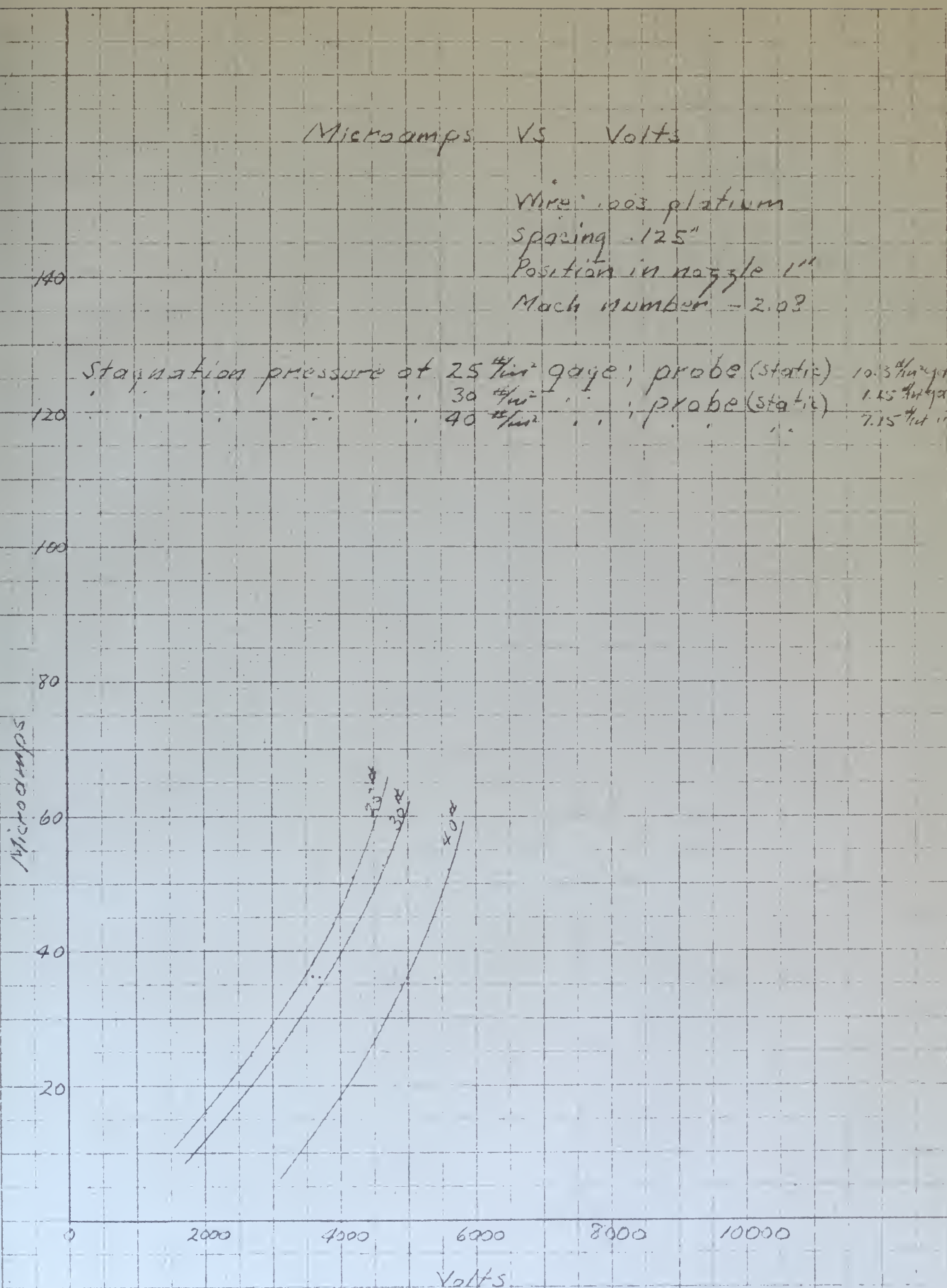


Fig-16-

Microamps VS Volts

.003 wire platinum

.125" spacing

2" position in nozzle

Mach number 2.49

Stagnation pressure at 40 $\frac{lb}{in^2}$ gage static probe 11.5 $\frac{lb}{in^2}$ gage

50 $\frac{lb}{in^2}$..

10.2 $\frac{lb}{in^2}$..

60 $\frac{lb}{in^2}$..

9.2 $\frac{lb}{in^2}$..

Microamps

140

120

100

80

60

40

20

0

2000

4000

6000

8000

10000

Volts

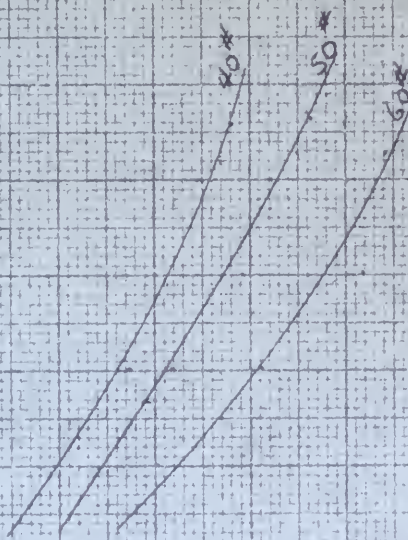


Fig-17-

Microamps VS Volts

Wica, 1003 platinum
 scaling 12.5
 Mach number 2.81
 position in nozzle 3"

stagnation pressure of 70 $\frac{\text{ft}}{\text{min}}$ gage static probe 11.7 $\frac{\text{ft}}{\text{min}}$ gage
 80 $\frac{\text{ft}}{\text{min}}$ " " 11.0 $\frac{\text{ft}}{\text{min}}$
 90 $\frac{\text{ft}}{\text{min}}$ " " 10.2 $\frac{\text{ft}}{\text{min}}$

Microamps

70*

80*

90*

140

20

0

2000

4000

6000

8000

10000

Volts

Fig-1B-

Microamps Vs Volts

Wire .003 platinum
Spacing .125
Noch number - 3.1
position in 1133/10 4"

Stagnation pressure of 90 $\frac{\text{lb}}{\text{in}^2}$ static probe 12.4 $\frac{\text{lb}}{\text{in}^2}$
" " " 94 $\frac{\text{lb}}{\text{in}^2}$ " " 12.1 $\frac{\text{lb}}{\text{in}^2}$
" " " 100 $\frac{\text{lb}}{\text{in}^2}$ " " 11.57 $\frac{\text{lb}}{\text{in}^2}$

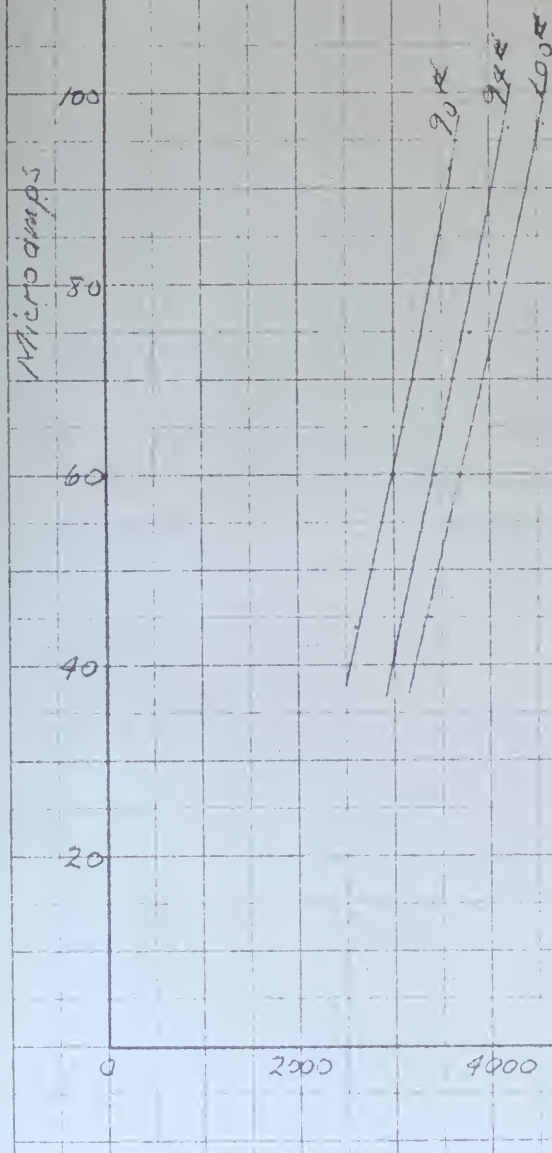


Fig-19-

absolute pressure vs Volts

Mach number = 2.08
 Spacing = 125 inches
 Wire = 003 platinum

absolute pressure inches hg

1000g

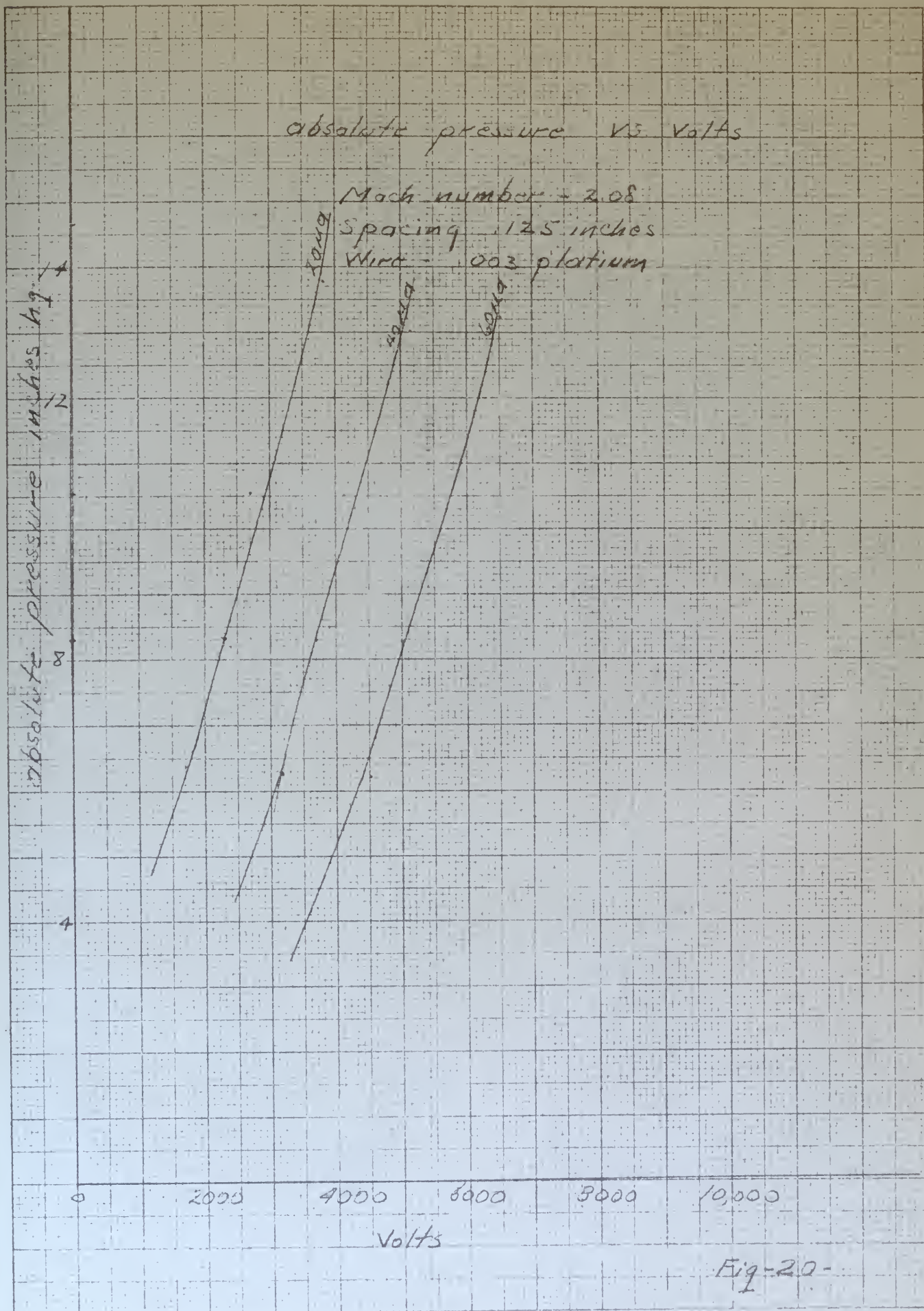
4000g

6000g

0 2000 4000 6000 8000 10,000

Volts

Fig-20-



absolute pressure vs Volts

Mach number 2.44

Spacing .125 inches

Wire .003 platinum

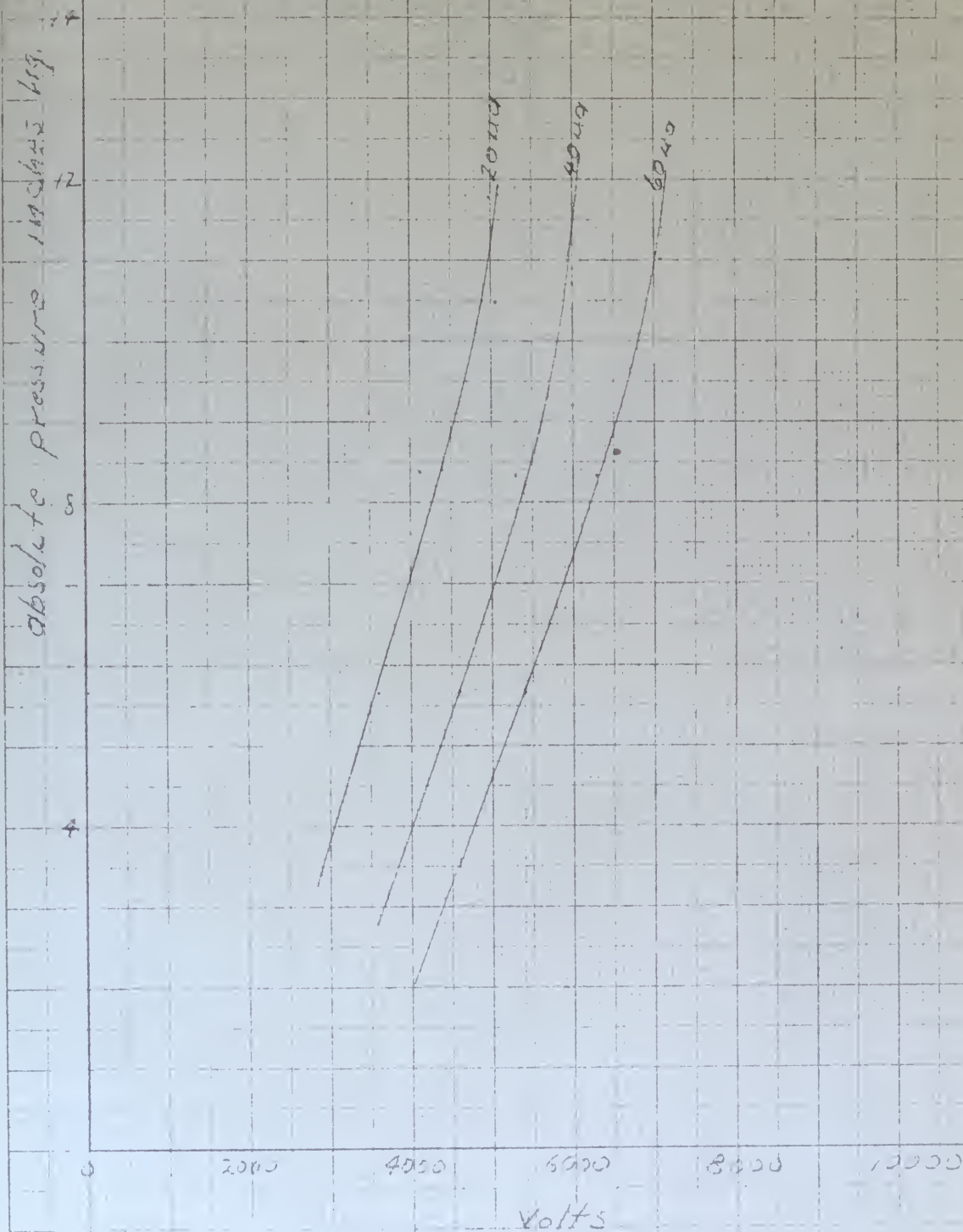


Fig-21-

absolute pressure vs. Volt

Mach number 2.81

Spacing .125 inches

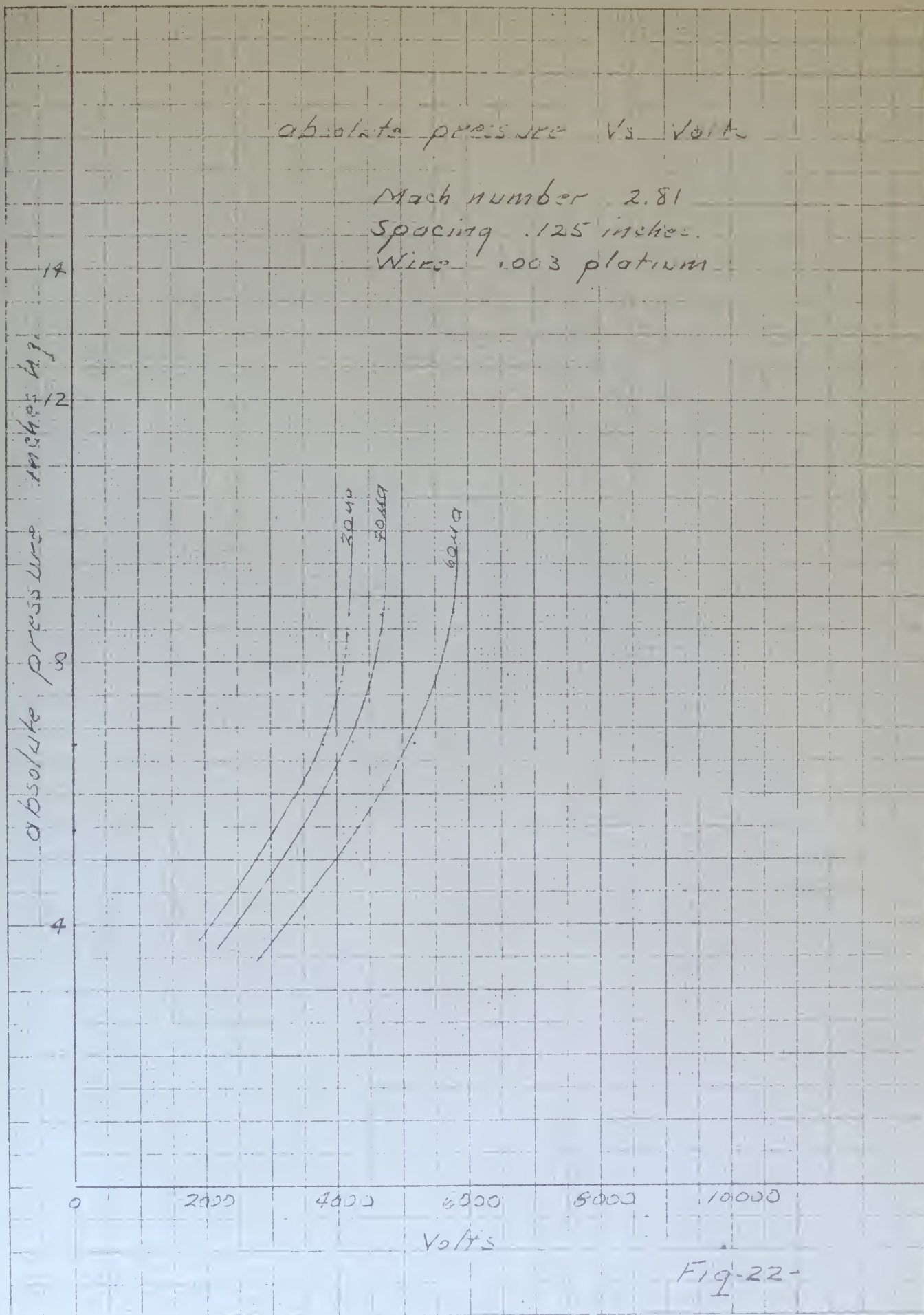
Wire .003 platinum

absolute pressure inches Hg

0 2000 4000 6000 8000 10000
Volts

5000
4000
3000

Fig-22-



absolute pressure vs Volts

Mach number 3.1

Spacing .125 inches

Wire .003 platinum

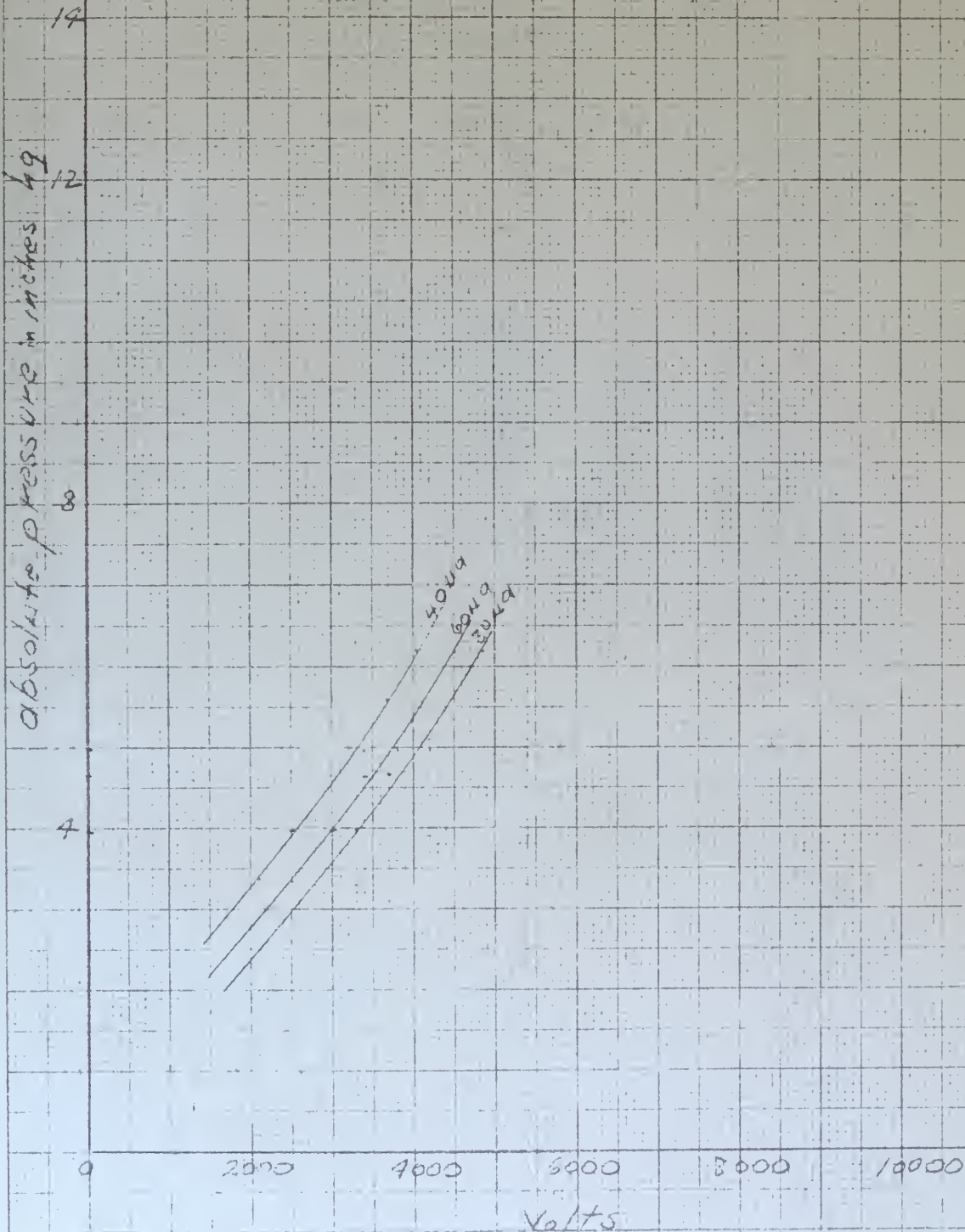


Fig-23-

Microamps vs Volts at const. abs. Pressure
absolute pressure = 5 inches hg.

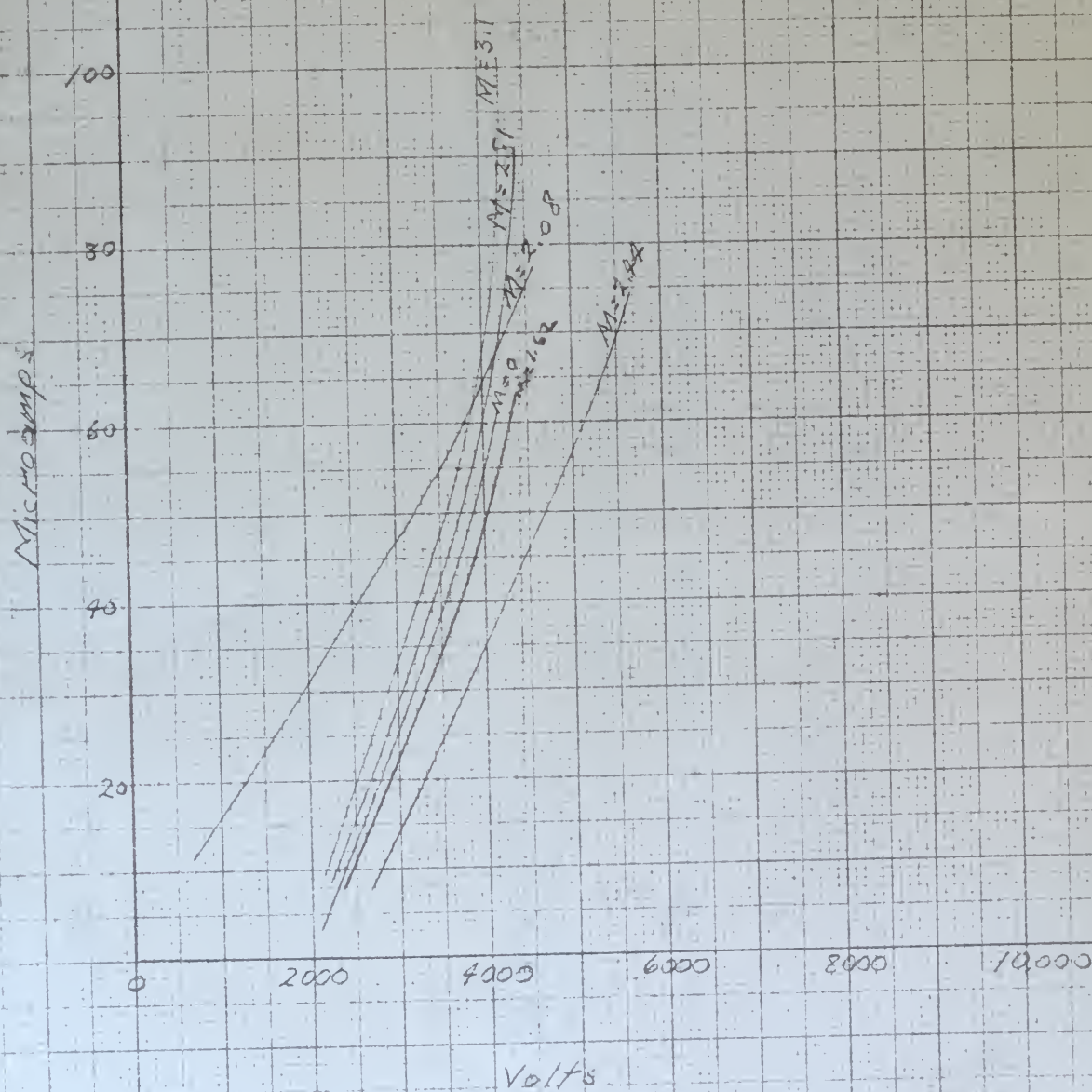
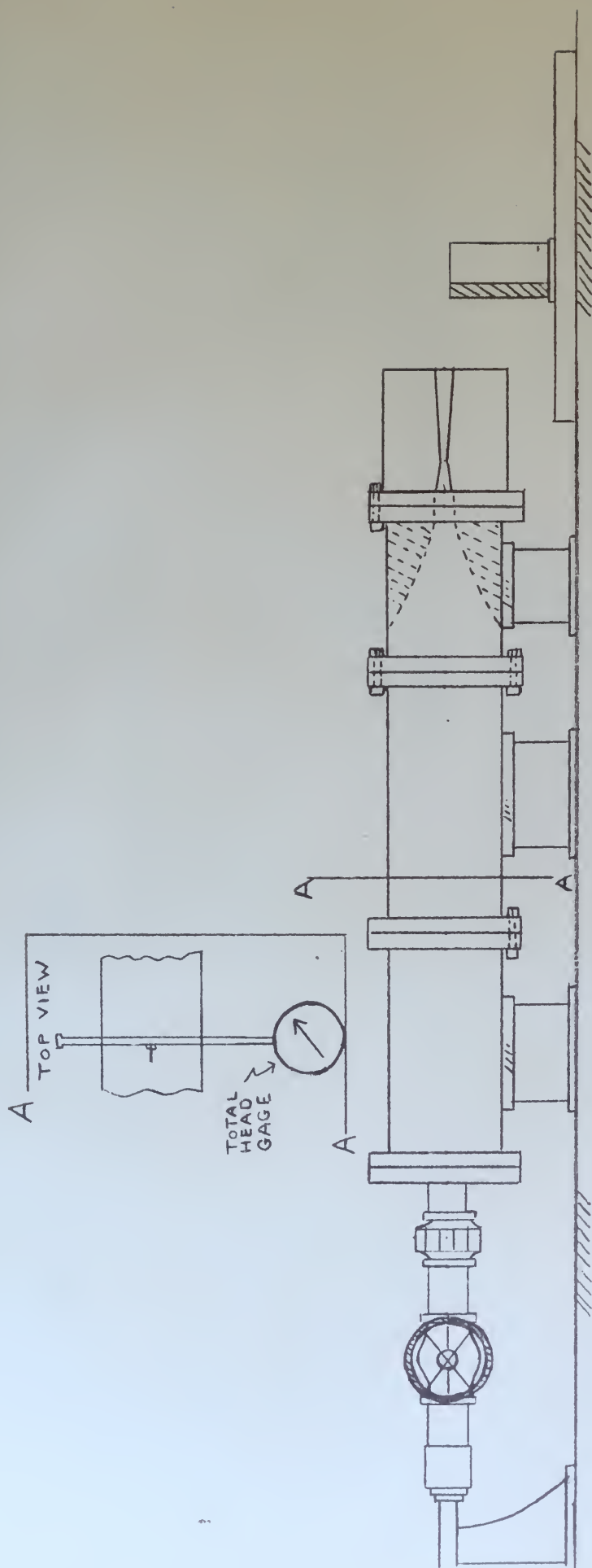


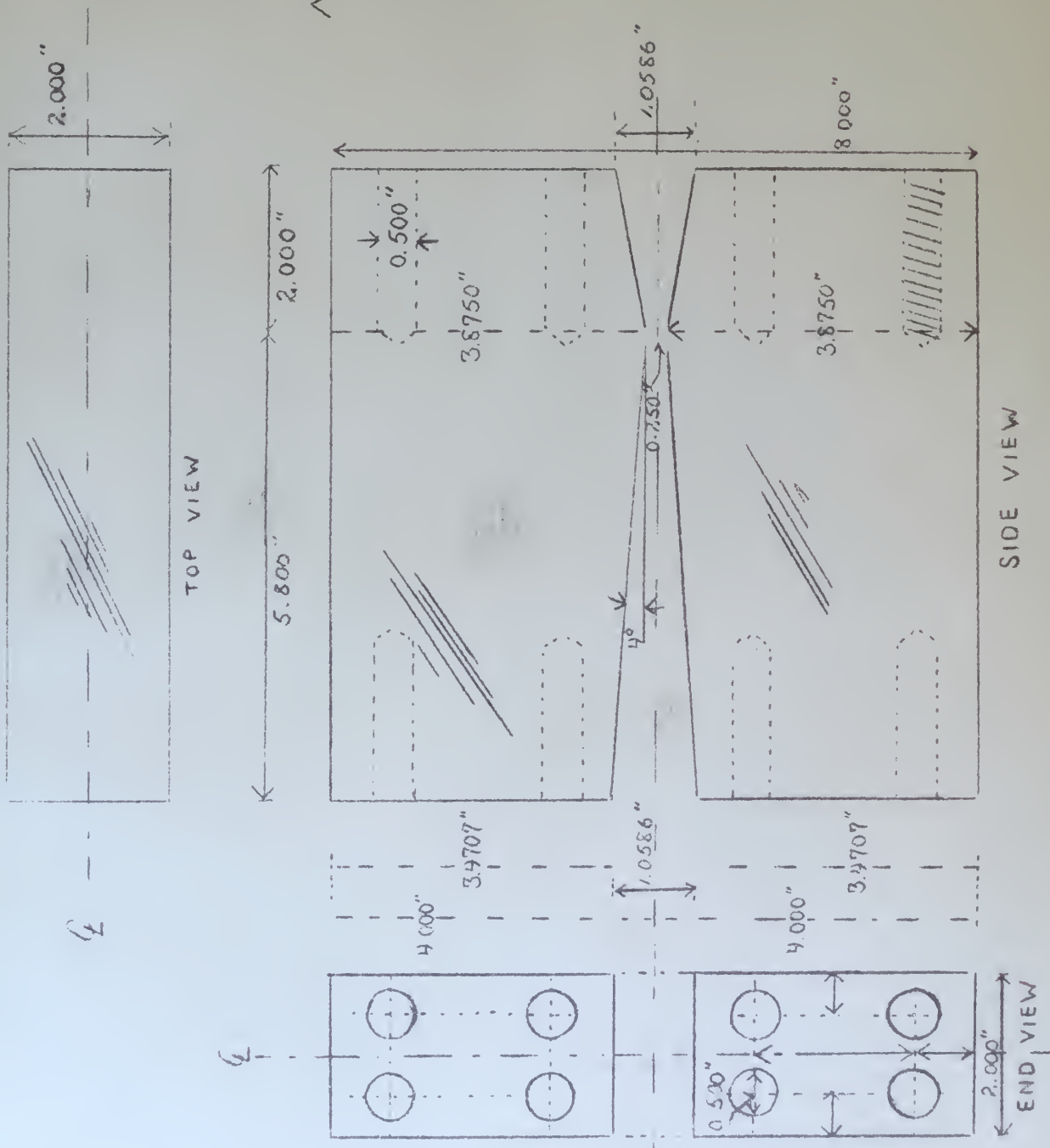
Fig-24-

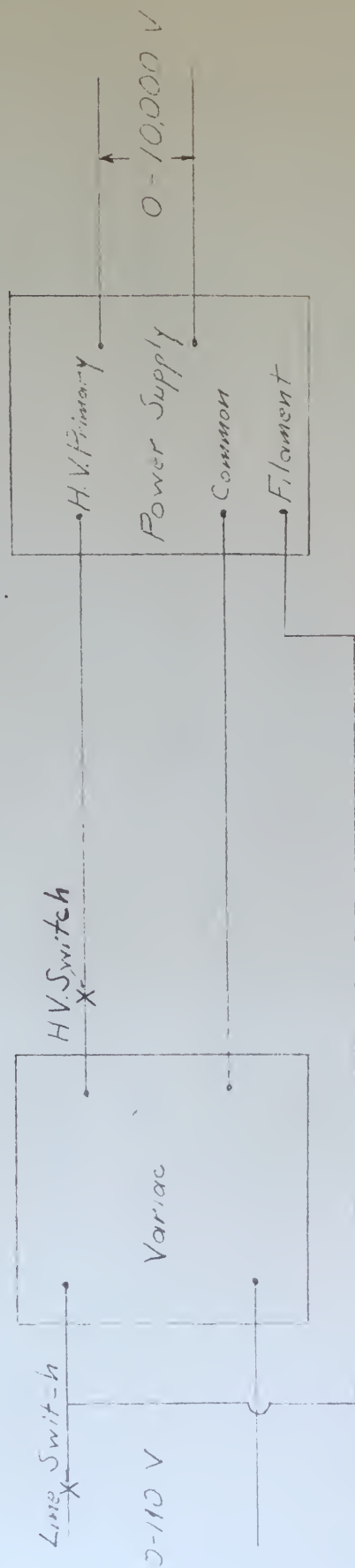


SCALE $\frac{1}{10}'' = 1''$

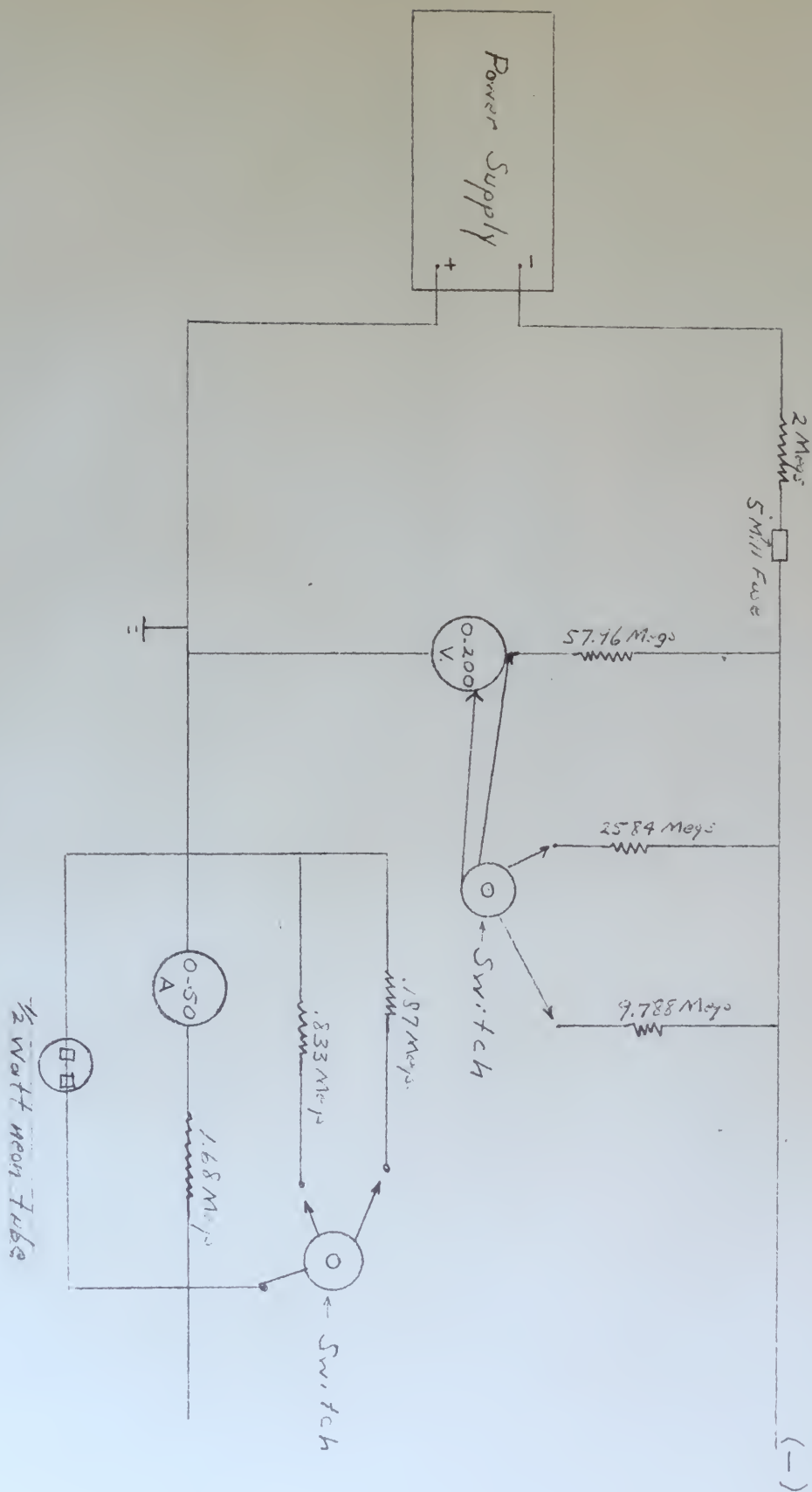
SIDE VIEW
WIND TUNNEL

NOZZLE BLOCK DESIGN

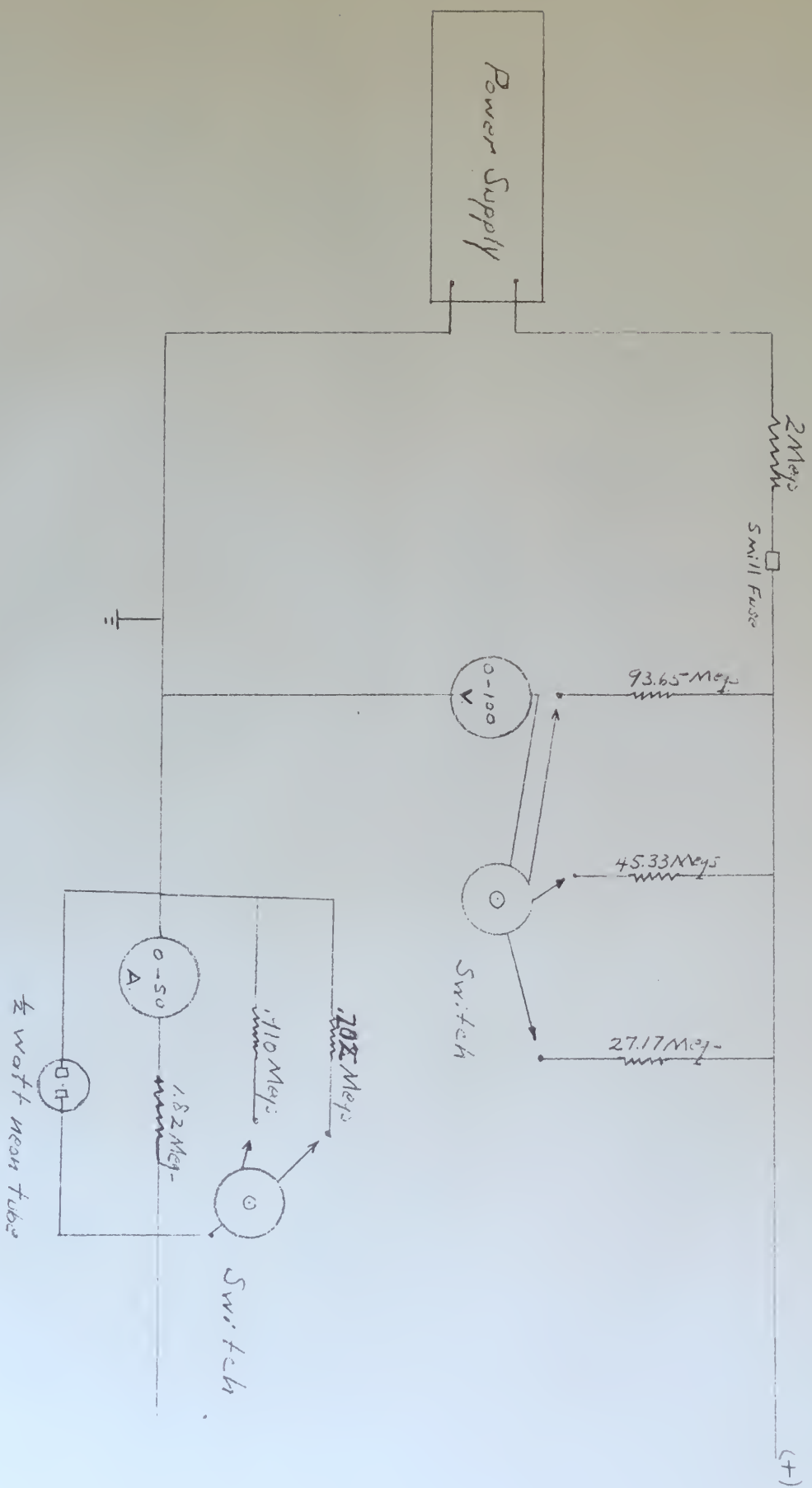




Power Supply

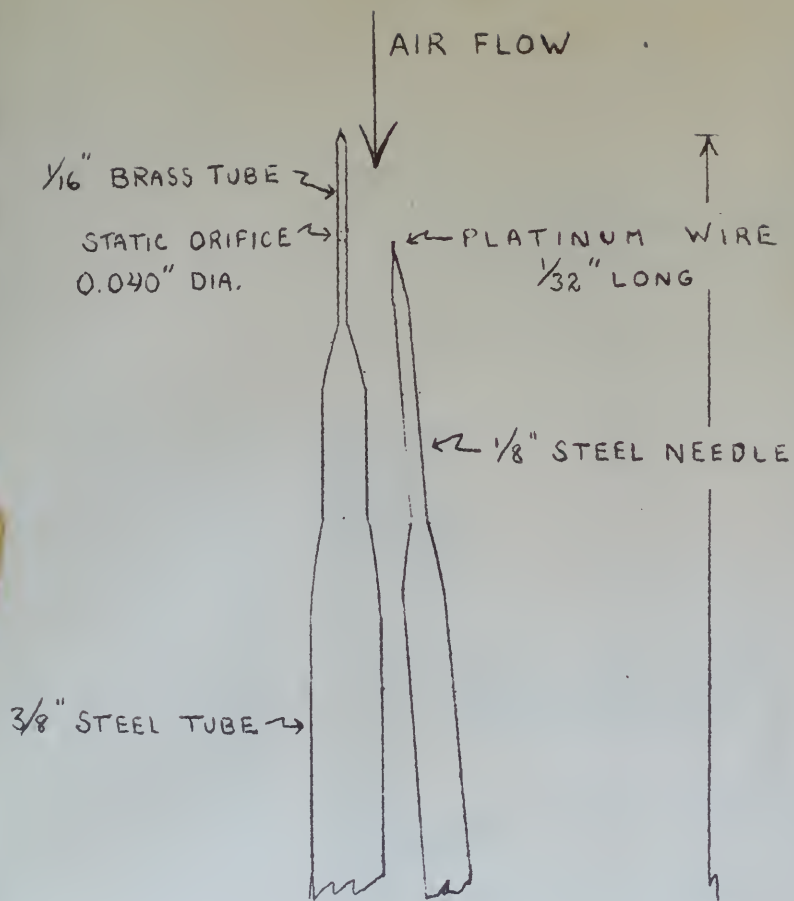


Circuit # 1

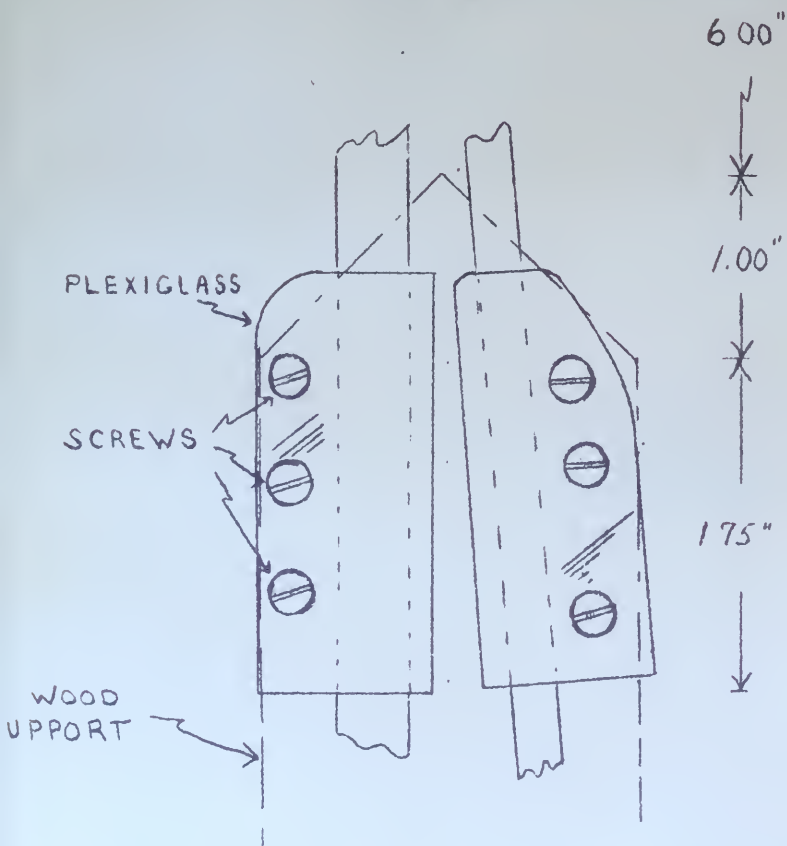


Circuit

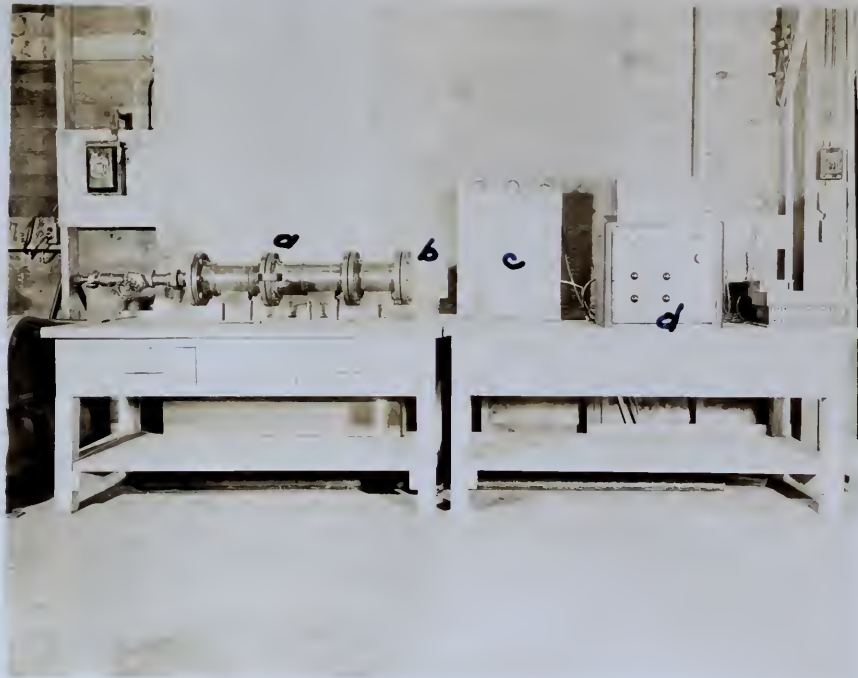
2



ARRANGEMENT of
the PROBES



WIND TUNNEL & ELECTRONIC EQUIPMENT



- a - Stagnation Chamber
- b - Nozzle
- c - Manometer Board
- d - Electronic Equipment

Fig. 31

THE JOURNAL OF THE AMERICAN MEDICAL ASSOCIATION



1 - American Medical Association
 2 - Board of Directors
 3 - American Medical Association
 4 - American Medical Association

NOZZLE BLOCKS, PROBES & VACUUM JAR

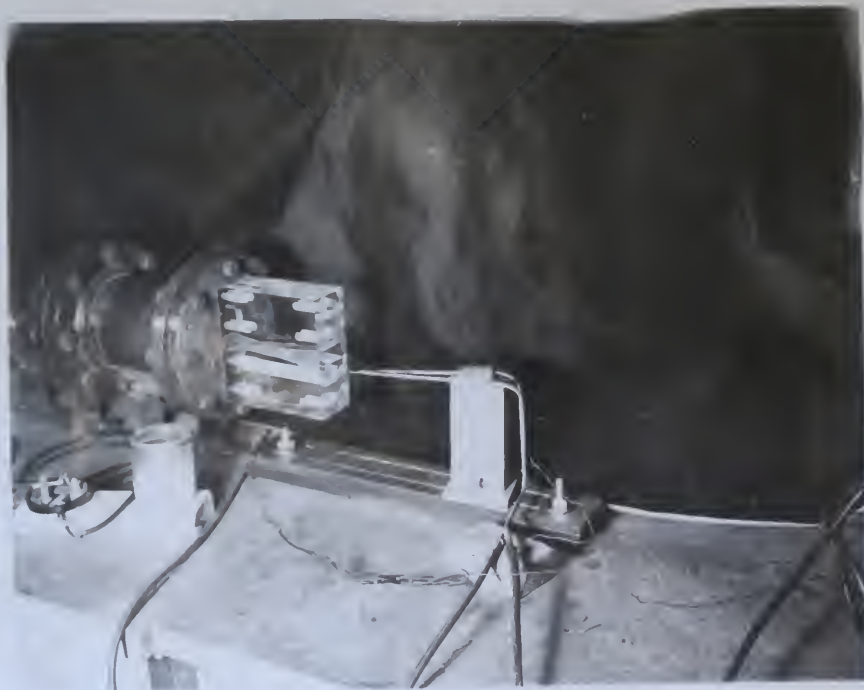
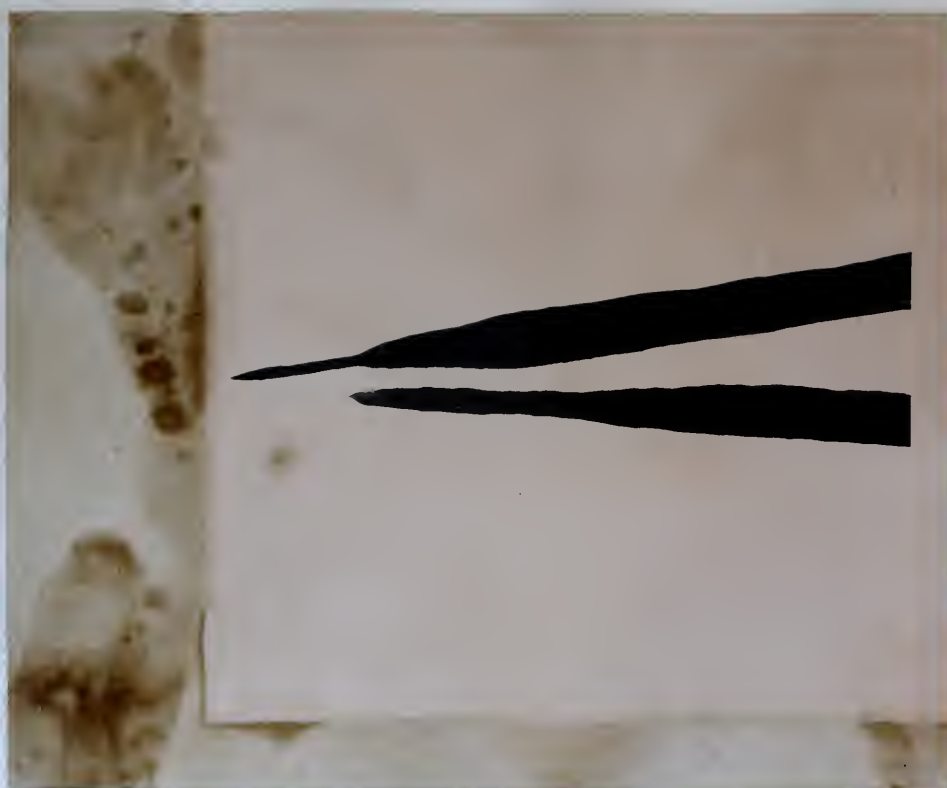


Fig. 32

THE HISTORY OF THE





Static Probe

Platinum Wire
Probe

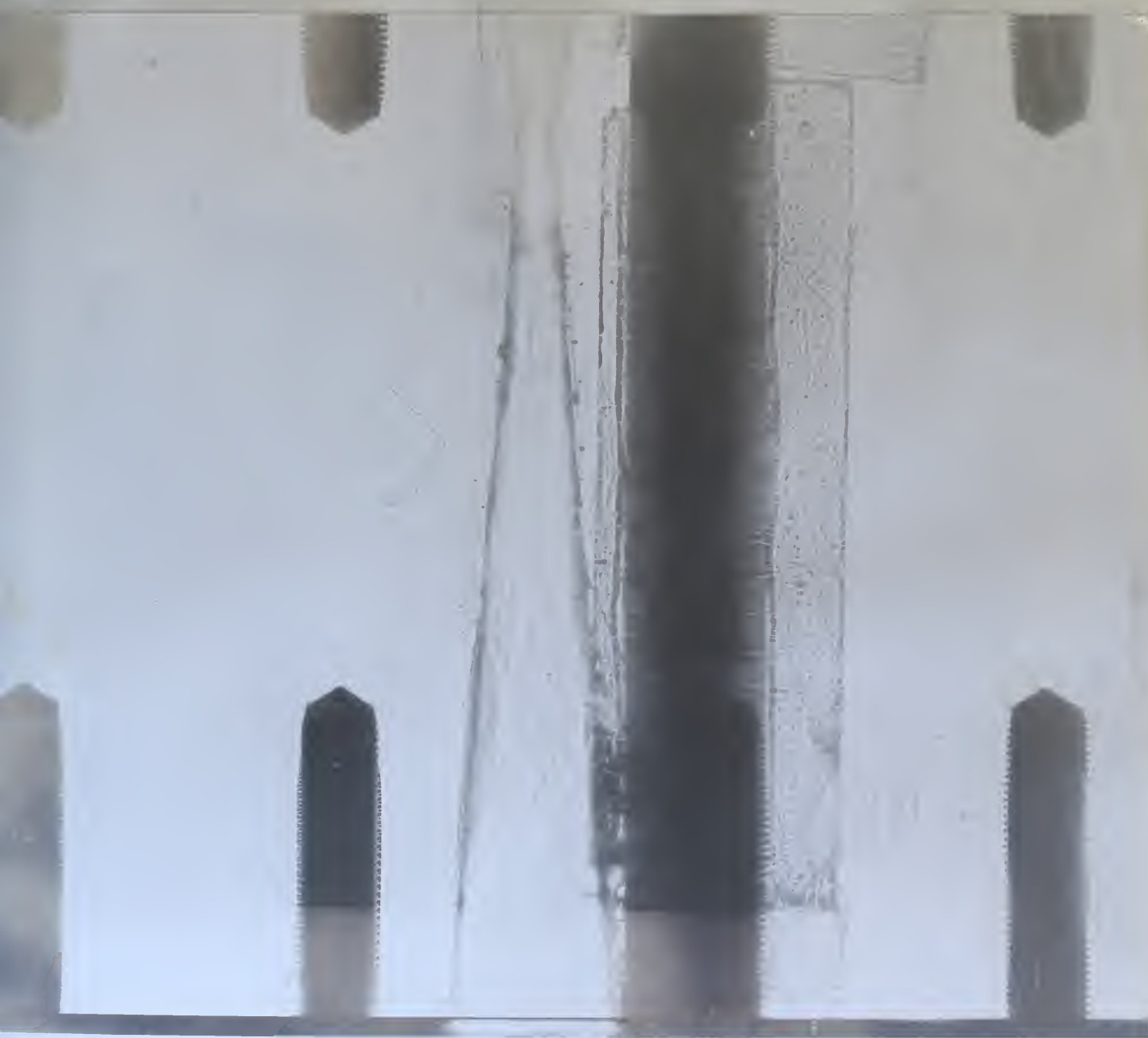
PROBES, SPARK PHOTOGRAPH

Specimen No. 100

Specimen No. 101



Specimen No. 102





$M = 2.81$; Stagnation Pressure 90#/in.² gage



Prober Inserted
 $M = 2.81$ Stagnation Pressure 90#/in.^2 gage

Fig. 36

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